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Nine-Year Summary of Fort Irwin, CA, Family Housing Comparison Test: Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units

by
Robert D. Neathammer

To determine if manufactured/factory-built family housing is more cost-effective in providing housing than conventional construction, Congress directed that a test of construction methods be conducted. In 1982, Congress authorized the construction of 200 units of manufactured/factory-built housing at Fort Irwin, CA, and concurrently, 144 units of conventionally built units.

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The Assistant Secretary of the Army for Installations, Logistics, and Environment requested that the study be extended beyond the 5 years. This report compares the first 9 years of O&M costs.

Through 9 years of occupancy, maintenance costs for the manufactured housing were significantly higher than for the conventionally built housing, with defective water piping a major problem.

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FOREWORD

This research was conducted for the U.S. Army Center for Public Works (USACPW), under the following Intra Agency Orders (IAOs) from Fort Irwin and Headquarters, U.S. Army Forces Command (FORSCOM): FHAA022-83, dated August 1983; R039-84, dated May 1984; S040-85, dated January 1985; T016-86, dated November 1986; CERL-87, dated December 1987; CERL-88, dated June 1988; CERL-89, dated 2 March 1989; Headquarters, U.S. Army Corps of Engineers (HQUSACE) FAD 90-080031, dated September 1990; (HQUSACE) FAD 91-080025, dated September 1991, (HQUSACE) FAD 92-080020, dated 10 Aug 92 and (HQUSACE) FAD 93-080024, dated 17 Sep 1993. The USACPW technical monitor was Alex Houtzager (CECPW-HM-O). Other technical advisors from USACPW were Robert Lubbert and Joe Hovell. Coordination and advice from FORSCOM were provided by Bill Mann, FCEN-RDM. The Fort Irwin advisors were Tom Cragg and Walt Perry.

The work was performed by the Facility Systems Division (FF), of the Infrastructure Laboratory (FL), U.S. Army Construction Engineering Research Laboratories (USACERL). The principal investigator was Robert Neathammer, CECER-FFR. Alan Moore is Acting Chief, CECER-FF. Dr. Michael J. O'Connor is Chief, CECER-FL. Valuable assistance was provided by Robert F. Doerr, Jr., CECER-FF.

LTC David J. Rehbein is Commander of USACERL and Dr. L.R. Shaffer is Director.

CONTENTS

CONTENTS (Cont'd)

FIGURES

TABLES

NINE-YEAR SUMMARY OF FORT IRWIN, CA, FAMILY HOUSING COMPARISON TEST: OPERATION AND MAINTENANCE COSTS OF MANUFACTURED vs. CONVENTIONALLY BUILT UNITS

1 INTRODUCTION

Background

Congress believes that use of manufactured (factory built) military housing, rather than conventionally built units, will result in lower overall costs and provide durable housing that meets contemporary housing standards. To verify this belief, Congress directed the Department of Defense (DOD) to construct 200 units of manufactured housing at Fort Irwin, CA, and compare them with similarly designed, conventionally built housing.[1] DOD was also directed to perform a study comparing the operation and maintenance (O&M) costs of the two types of construction over a 5-year period. The conditions and parameters for this test were submitted to Congress.

Results of the 5-year study showed no difference in O&M costs between the two types of construction. However, the Assistant Secretary of the Army for Installations, Logistics, and Environment, and managers at the U.S. Army Center for Public Works (USACPW), and the U.S. Army Construction Engineering Research Laboratories (USACERL) thought 5 years is too short a time for valid comparisons of O&M costs. Thus, USACERL was asked to continue collecting and analyzing data and to report results at the end of each year in order to identify broad trends. Ten years data will be collected.

The manufactured units met Federal Manufactured Housing Construction and Safety Standards (FMHCSS); however, upgrades in certain criteria were specified to bring the units into conformance with DOD standards. These areas of concern included net usable floor space, energy efficiency, fire and life safety, and durability of certain materials and components. The study compared the impact of the modified FMHCSS versus standard DOD criteria, except for the essential criteria listed in the previous sentence.

The study began when the housing units were first occupied; initial occupancy of some units started in February 1983. The study compares 200 two-bedroom manufactured units to 144 two-bedroom, conventionally built units. The two types of units were similar in floor area, floor plans, and materials used.

The data collected address O&M costs for both types of housing. The study identifies not only the differences, if any, in O&M costs, but also the reasons for the differences and their importance for future construction criteria and construction methods.

Objective

This report summarizes the O&M costs for both conventionally built and manufactured housing from construction through the first 9 years of occupancy.

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[1] Report No. 97-44, *Military Construction Authorization Act* (House of Representatives Committee on Armed Services, 1982), pp 8-9.

Approach

The first step was to develop uniform data collection and data analysis procedures. The cost comparisons and analyses for this study were established in USACERL Special Report (SR) P-140.[2] Data were collected throughout the study and summarized/reported yearly. First-year data were reported in USACERL Interim Report (IR) P-85/14;[3] second-year data in USACERL IR P-86/06;[4] third-year data in USACERL IR P-87/10;[5] fourth-year data in USACERL IR P-88/09;[6] 4 1/2-year data in USACERL IP P-89/14;[7] fifth-year data in USACERL TR P-90/11;[8] sixth-year data in USACERL TR P-91/37;[9] seventh year date in USACERL TR FF-92/08,[10] and eighth year data in USACERL TR FF-93/09. [11]

Individuals were assigned to quarters with no distinction between the two types of units. The units all have the same floor area and were to be occupied by essentially the same ranks/ages of sponsors; assignment of families was not biased by the type of construction.

Scope

Study costs were limited to the buildings themselves, as the intent of the study was to compare O&M costs of the two types of construction. Thus, sidewalks, driveways, streets, lawns, playgrounds, and utility lines outside the buildings were not included. Also, the replacement costs of refrigerators, kitchen stoves, and utility meters were excluded. (Because of these exclusions, the unit cost data in this report *is not comparable* to standard unit cost data reported for family housing in many Army financial reports, which normally includes costs such as streets and utility lines.)

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2 M.J. O'Connor, *Fort Irwin Housing Comparison Test*, Special Report (SR) P-140/ADA130349 (USACERL, 1983).

3 R.D. Neathammer, *Fort Irwin, CA, Family Housing Comparison Test: Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units*, Interim Report (IR) P-85/14/ADA159740 (USACERL, 1985).

4 R.D. Neathammer, *Two-Year Summary of Fort Irwin, CA, Family Housing Comparison Test: Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units*, IR P-86/06/ADA175995 (USACERL, 1986).

5 R.D. Neathammer, *Three-Year Summary of Fort Irwin, CA, Family Housing Comparison Test; Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units*, IR P-87/10/ ADA180001 (USACERL, 1987).

6 R.D. Neathammer, *Four-Year Summary of Fort Irwin, CA, Family Housing Comparison Test; Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units*, IR P-88/09/ADA190017 (USACERL, 1988).

7 R.D. Neathammer, *May 1984 to September 1988 Summary of Fort Irwin, CA, Family Housing Comparison Test: Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units*, IR P-89/14/ADA209421 (USACERL, 1989).

8 R.D. Neathammer, *Five-Year Summary of Fort Irwin, CA, Family Housing Comparison Test: Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units*, TR P-90/11/ADA222176 (USACERL, 1990).

9 R.D Neathammer, *Six-Year Summary of Fort Irwin, CA, Family Housing Comparison Test: Operation and Maintenace Costs of Manufactured vs. Conventionally Built Units*, TR P-91/37/ADA237479 (USACERL, 1991).

10 R. D. Neathammer, *Seven-Year Summary of Fort Irwin, CA, Family Housing Comparison Test: Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units*, TR FF-92/08/ADA256255 (USACERL, 1992).

11 R. Neathammer, *Eight-Year Summary of Fort Irwin, CA, Family Housing Comparison Test: Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units*, TR FF-93/09/ADA273102 (USACERL, 1993).

2 REVIEW OF TEST PLAN

USACERL SR P-140 detailed the cost data collection plan and analysis methods. Four basic questions on costs will be answered:

1. Were the average annual O&M costs significantly different?

2. If different, where were they significantly different?

3. Why did the costs differ?

4. What criteria, design features, etc., need to be changed as a result?

Overall maintenance costs and utility costs were compared separately. If significant differences were found, it was important to determine their causes.

In addition to the overall cost comparison, the maintenance costs for major building components were compared. These comparisons provide more detail about where and why cost differences occur.

Occupant satisfaction with the overall apartments and each physical part of the unit was compared for the two types of construction and reported in USACERL P-90/11. When occupant satisfaction differed for a building component, that component was evaluated to determine the reason for the difference.

3 DESCRIPTION OF THE FAMILY HOUSING UNITS

Manufactured Housing Units (MHUs)

These 200 units consist of 50 two-story fourplexes (two units on each of the first and second floors). Net floor area is 950 sq ft/unit.* These were constructed on perimeter footings with wood floors and crawl spaces. Each upper unit has a balcony-porch and each lower unit has a patio with privacy fencing. Figure 1 shows front and rear views of typical buildings. Each unit has a refrigerator, gas range, gas water heater, garbage disposal, dishwasher, central air conditioning, and gas-fired forced-air furnace (all provided by the contractor). Each unit has two bedrooms, a kitchen, living-dining area, one bathroom, a utility room, and a one-car garage. The garage was constructed on site.

A detailed description of the construction process including photographs and floor plans for the units is shown in Appendix A.

The notice to proceed date was 10 January 1983. Initial occupancy was:

61	units	Dec 83
7	units	Jan 84
64	units	Feb 84
57	units	Apr 84
9	units	May 84
2	units	Jun 84

Conventionally Built Units (CBUs)

The 144 units consist of 13 sixplexes, 6 fiveplexes, and 9 fourplexes, all two-story buildings. Net floor area is 950 sq ft/unit. These units were constructed on perimeter footings with building slab. Each unit has two bedrooms, a kitchen, living-dining area, one bathroom, utility room, either a fenced patio or balcony-porch (for upper unit), and a one-car garage. Figure 2 shows front and rear views of typical buildings. The fourplexes have two units on each level. There are two units on the second story in the five- and sixplexes with the additional unit(s) on the first level. The CBUs also have a refrigerator, gas range, gas water heater, garbage disposal, dishwasher, central air conditioning, and gas-fired forced-air furnace.

The notice to proceed date was 3 May 1982. Initial occupancy was:

8	units	Feb 83
28	units	Mar 83
38	units	Apr 83
31	units	May 83
23	units	Jun 83
14	units	Jul 83
2	units	Aug 83

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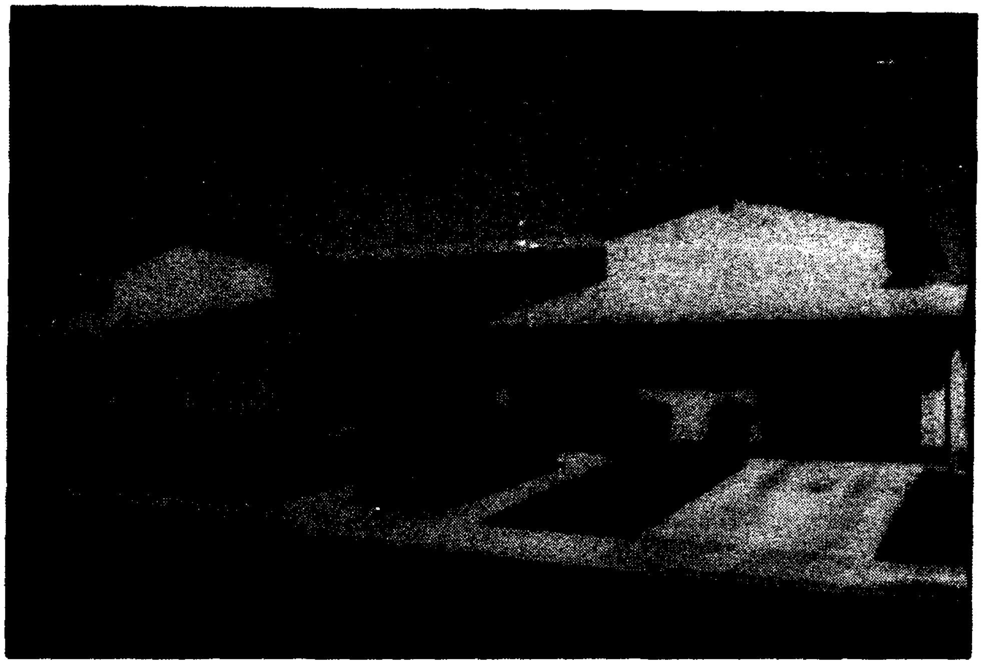
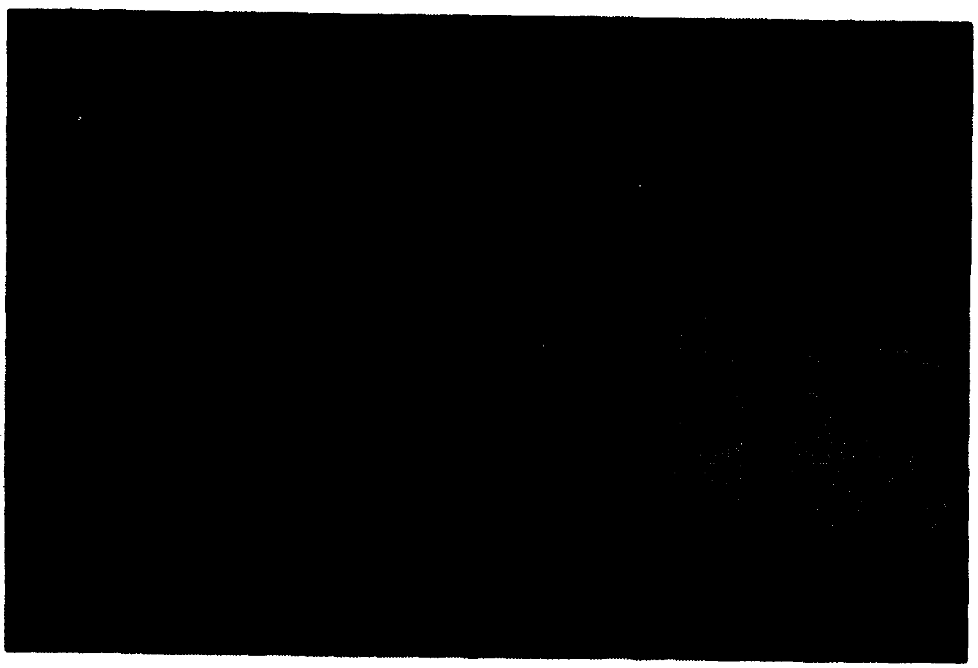
* **Metric conversions:** 1 cu ft = 0.028 m^3; 1 sq ft = 0.093 m^2; °C = 0.55 x (°F-32).



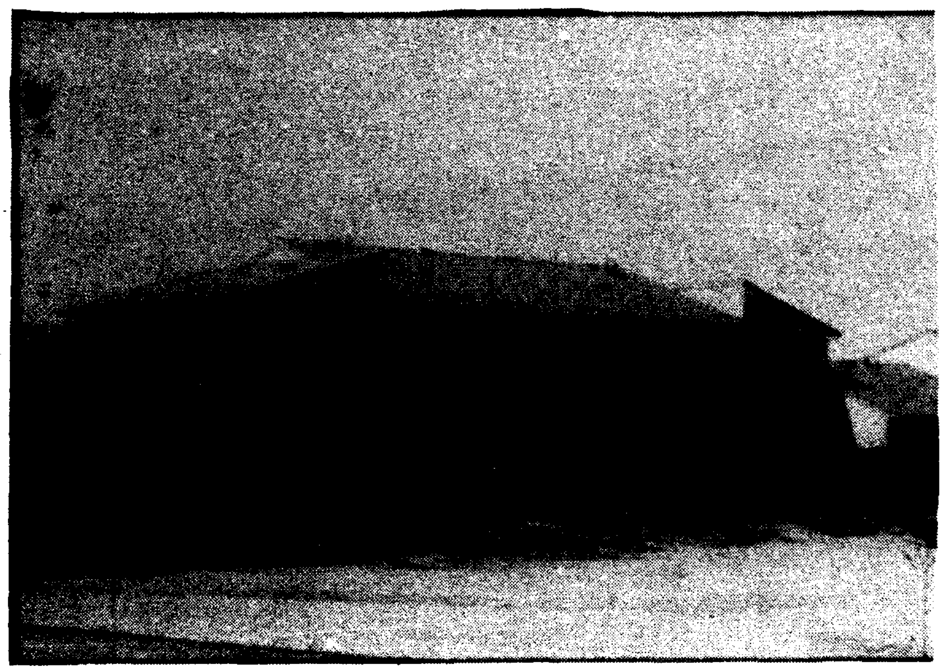
Front View - MHU



Rear View - MHU

Figure 1. Front and rear views of typical MHUs.

Front View - CBU



Rear View - CBU

Figure 2. Front and rear views of typical CBUs.

A detailed description of all units can be found in the Los Angeles District Office report.[11] The buildings were not specifically adapted to the desert environment but are typical Southern California design.

Costs

A clear-cut initial cost comparison of the two unit types was not possible. The 144 CBUs were part of a project of 254 units. The cost for this project was $51.83/sq ft. The 200 MHUs costs were $51.22/sq ft. However, the supervision and administration costs for the MHUs were based on the same 5 percent rate used for the CBUs. More labor was required since quality assurance inspection was required at the manufacturing plant as well as at the construction site. It was estimated that the additional labor would have raised the cost to $55/sq ft (no records were kept as these are all indirect costs).

General Comparison

Fort Irwin is located in a high desert environment. Annual rainfall averages 4 in. and temperatures often exceed 100 °F. The housing construction was not adapted to this climate but is representative of Southern California design.

The exterior finish of both unit types is stucco with some brick veneer on the garages. Exterior trim is painted wood. Asphalt shingles were used on both types, and gutters and downspouts were installed.

Interior walls are painted gypsum board. Floors on the second level are carpeted and are vinyl tile or vinyl sheet covering on the first floor.

Water piping is copper in the CBUs and polybutylene in the MHUs.

Windows are single pane in the MHUs and thermal pane in the CBUs.

First-story floors in MHUs are wood on crawl spaces and in CBUs are concrete slabs.

Grass was planted in the immediate yard area of the buildings, but not in play yard areas. Each first-floor unit has a concrete patio with a wooden privacy fence; each second-story unit has a wooden balcony-porch.

[11] *Fort Irwin Family Housing Study--A Report on Manufactured/Factory-Built Housing and Site-Built Housing, Fort Irwin, CA* (U.S. Army Corps of Engineers, Los Angeles District, September 1984).

4 DATA COLLECTION PROCEDURES

Data were collected in enough detail that any differences found between the two types of construction could be explained. Appendix B lists the housing units and their identification numbers used in the data collection. Appendix C lists the building components and subcomponents. Each service order was coded to a component so the costs of components could be compared. A discussion of the data collected is included in USACERL SR P-140.

Data Collection

Discussions were held with representatives of the USAEHSC technical monitor; Forces Command Headquarters; Fort Irwin personnel; and the base operations contractor, Boeing Services International (BSI); to establish the best methods of collecting the data.

BSI was contracted to segregate all maintenance service orders for the test units and report the cost data to USACERL through the Fort Irwin Directorate of Engineering and Housing (DEH) monthly. BSI was also contracted to read gas and electric meters at the end of each month and report similarly.

A new contractor, Dynalectron, became the base operations contractor effective 1 October 1986 and has performed the same services.

Data Verification

USACERL verified the reported data several ways. For the first 5 years, each original work order (WO) document was checked against the reported data forwarded by the contractor. Discrepancies were resolved on verification visits to Fort Irwin. Additionally, the contractor set up separate accounting codes for the two groups of units and the total billed was compared to the total obtained from summing all the individual WO data. For years 6 through 8 the reported data was checked for obvious errors, which were resolved with the contractor. No detailed validation of each WO was made as the purpose of the continued study is to search for overall trends.

USACERL developed a computer program to compare gas and electricity meter readings. When apparently erroneous data occurred, the contractor was notified and corrections were made.

Data Analysis

Maintenance Costs

Maintenance costs were compared on a unit-month basis and yearly basis. The data were also summarized by building component to determine if one or more components for one of the types of units had large maintenance costs. If so, the reasons for these costs were determined to help define what criteria or design features should be reviewed/changed.

Cost differences could have been caused by material quality, installation, differences inherent to manufactured or conventional construction, and possible errors in specifications for the two projects.

Warranty work referred to the construction contractor was not included in the cost comparison since no cost data were available or applicable, as it was not a cost to the government. However, the cost of a service call to assess a problem was included.

Energy Consumption

Gas and electricity consumption were compared on a quarterly basis and a yearly basis. Since most of the MHUs were not completed until May 1984, prior energy consumption data for the CBUs was not used in comparisons. (Energy consumption comparisons are valid only for the same time frame because of varying weather conditions.)

5 WHOLE HOUSE ENERGY TESTS

Energy evaluations of sample units of each type of construction were performed immediately after construction was completed on each of the two groups of housing and again after 5 years of occupancy. The objective was to determine if energy characteristics had changed over the 5-year period. Three whole-house energy tests were performed. Appendixes D and E give details of the tests for the CBUs and MHUs, respectively.

House Tightness

The number of air changes per hour were measured with the following results:

	Immediately After Construction			After 5 Years		
Type	No. Units	Average Air Change Per Hour	Standard Deviation (%)	No. Units	Average Air Change Per Hour	Standard Deviation (%)
CBU	15	13.0	1.06	15	12.1	1.70
MHU	12	10.9	2.67	14	9.7	1.60

A statistically significant difference existed between the two types of construction for both the initial and 5-year tests, the MHUs being more airtight on the average. Neither type of unit changed significantly over the 5 years. These results indicate that the MHUs should have had less air infiltration/leakage.

Furnace Efficiency

The furnace efficiency results were as follows:

	Immediately After Construction			After 5 Years		
Type	No. Units	Average Efficiency % Per Hour	Standard Deviation (%)	No. Units	Average Efficiency % Per Hour	Standard Deviation (%)
CBU	13	66.2	6.24	14	64.2	12.2
MHU	16	79.3	3.36	15	77.3	2.84

The furnace efficiencies of the MHUs were significantly higher than those of the CBU for both the initial and 5-year tests. Neither type of unit changed significantly over the 5 years.

Wall Heat Transfer Characteristics

This parameter was not initially measured for the CBUs because of unfavorable weather during the testing period. This parameter was calculated for both types of construction using the designed wall construction.

Type	No. Units	Average Heat Loss (Btu/hr-°F)
CBU	16	1072
MHU	15	1220

Summary

The whole-house energy tests did not conclusively indicate which type of unit would use less energy for heating/cooling. The CBUs are more energy efficient considering only the wall heat loss test, but the MHUs perform better when tested for air tightness and furnace efficiency. Additionally, the CBUs are built on concrete slabs while the MHUs have a crawl space. Houses on concrete slabs use less energy than houses on crawl spaces. This has an impact on the first floor units' energy use.

Therefore, the tests are inconclusive in predicting which type of construction would use more energy for heating/cooling.

6 OPERATION AND MAINTENANCE (O&M) COSTS

O&M costs for each type of unit were compared over the first 9 years of occupancy. The test period for CBUs was 1 August 1983 through 31 July 1992; the test period for MHUs was 1 June 1984 through 31 May 1993.

Overall Costs

The total housing unit-months and maintenance costs for the first 9 years of occupancy are shown in Table 1. (Maintenance includes all types of repairs and "preventive maintenance" performed.)

Discussion

The MHUs cost about $40/month more than the CBUs over the first 9 years of occupancy; the difference in cost per unit per year is $474. There were large increases in M&R costs in years 5, 7, 8, and 9. This is illustrated in Table 2, which shows M&R costs per year of occupancy.

Table 1

Unit/Month Costs in First 9 Years' Occupancy

Type	No. Unit Months	Total Cost ($)	Cost/Unit/ Month ($)	Cost/Unit/ Year ($)
CBU	15,552	717,905	46	554
MHU	21,600	1,850,217	86	1028

Table 2

Yearly M&R Costs by Type of Construction

Year	Total CBU ($)	Cost/Unit ($)	Total MHU ($)	Cost/Unit ($)
1	31,592	219	34,164	171
2	29,107	202	59,076	295
3	44,391	308	63,717	319
4	45,565	316	114,728	574
5	89,186	619	189,122	946
6	96,700	672	175,725	879
7	111,785	776	216,636	1083
8	104,370	725	474,394	2372
9	165,209	1147	522,655	2613
9-Year Total	717,905	554	1,850,217	1028

Costs per unit have been increasing over time. Figure 3 shows the cumulative costs per unit per month for ages 15 to 108 months, illustrating this trend. The costs for the MHUs increased faster than for the CBUs. This can also be seen in Figure 4, which shows total costs per unit per year.

Increased costs in years 5 and 8 were attributable partly to interior painting done in units vacated for the first time and in those which required painting on change of occupancy. Increased costs in years 8 and 9 for MHU's were due to water piping and roofing costs. Table 3 shows the painting costs per year of occupancy. Note the large increases for MHUs in year 5 and for CBUs in year 6. Painting costs for both increased again in year 9.

Table 4 lists the yearly costs excluding interior painting. This table shows that the MHUs' costs increased faster than the CBUs' through year 9. Both showed decreases in year 6 and increases in years 7, 8, and 9. Figure 5 displays this data.

Costs Excluding Certain Equipment Costs

Since the purpose of this study was to compare maintenance costs attributable to the method of construction, a comparison was made excluding certain costs. Table 5 gives the costs for the 9 years of occupancy of each type unit, excluding any costs for maintenance of water heaters, garbage disposals, dishwashers, ranges, range hoods, and refrigerators (equipment not part of the construction process).

The difference in cost per unit per year between types of construction is $347/year. Compared to the $474 in Table 1, this is a better estimate of the cost difference attributable to the type of construction.

Costs Excluding Interior Painting and Equipment Costs

In Table 6 equipment costs and painting costs are excluded. The difference for unit cost is $341 per year. Figure 6 graphs the data of Table 6.

Maintenance Per Component

Table 7 lists the frequencies of work orders and costs per building component for the two types of units. However, the costs are not directly comparable across the two types of units since there are 200 MHUs and 144 CBUs. Table 8 shows the cost data adjusted by multiplying the MHU costs by 0.72 (144/200). Also shown in Table 8 are the 9-year costs on a unit basis.

Table 8 shows that the total 9-year cost was less than $1000 for both construction types for 24 of the 78 components. For 38 of the other 54 components, the MHUs had a higher cost.

Most of the costs shown in Tables 7 and 8 were for building components independent of type of construction. For example, about $20K was spent on the ranges (#1003) for each type, $22K for CBUs and $61K for MHUs was spent on dishwashers (#1002), and over $25K was spent on light fixtures (#906) for each type. The most significant costs for components that differ for the types were roofing surface (#101), exterior/storm/screen doors (#209), resilient flooring (#301), interior drywall (#212), garage doors (220), bathroom/kitchen fixtures (#804), lavatories (#805), and water piping (803). Although a large difference existed for painting, this cost depended on rotation of occupants and occupant wear and tear. Complete or extensive quarters painting was done on 407 MHUs and only 243 CBUs.

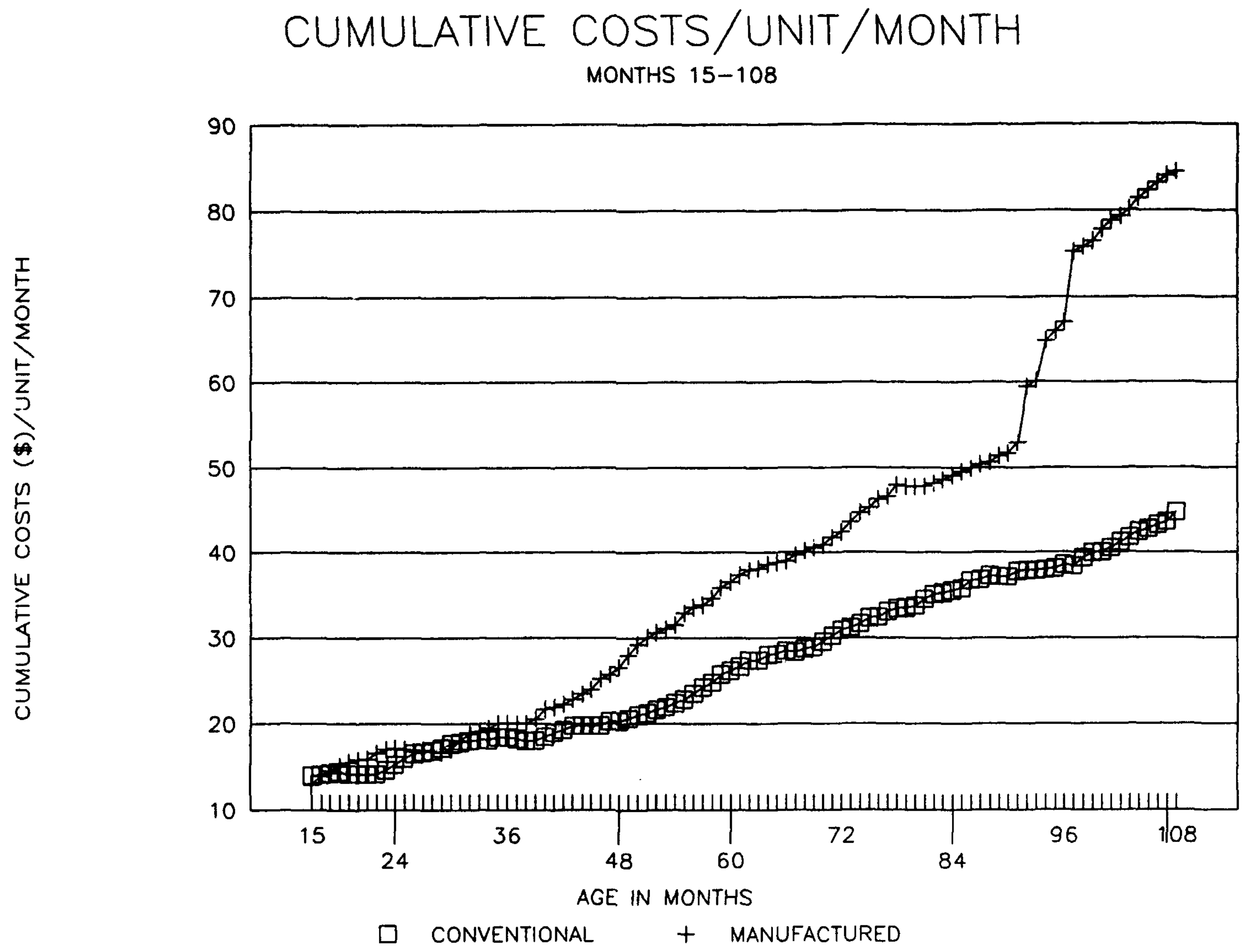


Figure 3. Cumulative cost per unit per month for ages 15 through 108 months.

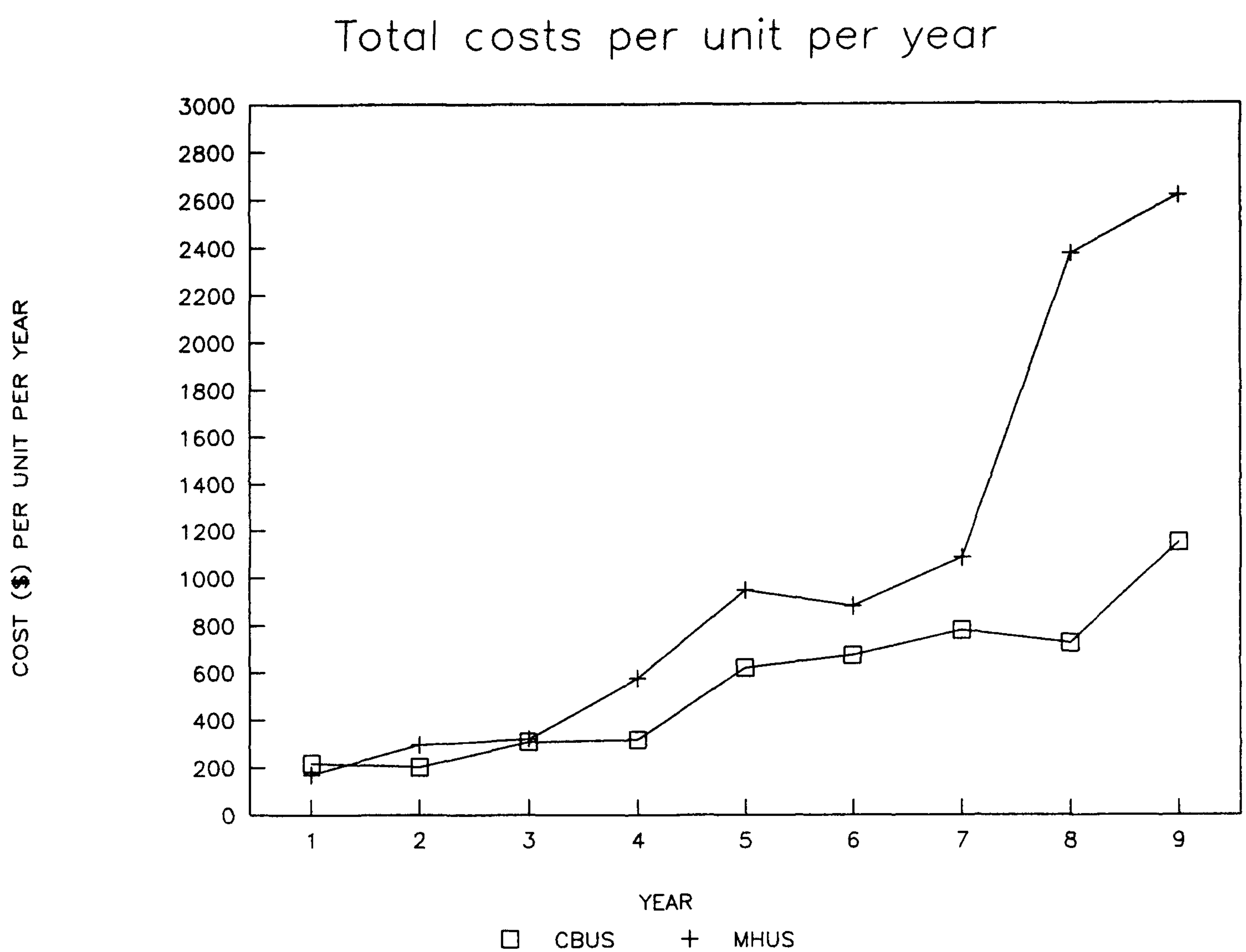


Figure 4. Total costs per unit per year.

Table 3

Interior Painting Costs

Year	Total CBU ($)	Cost/Unit ($)	Total MHU ($)	Cost/Unit ($)
1	603	4	314	2
2	1,234	9	4,486	22
3	7,031	49	13,231	66
4	11,368	79	24,343	122
5	29,720	206	80,485	402
6	49,445	343	74,764	374
7	53,235	370	67,676	338
8	29,583	205	76,157	381
9	55,128	383	102,533	513

Table 4

Yearly M&R Costs Excluding Interior Painting Costs

Year	Total CBU ($)	Cost/Unit ($)	Total MHU ($)	Cost/Unit ($)
1	30,989	215	33,850	169
2	27,873	194	54,590	273
3	37,360	259	50,486	252
4	34,197	237	90,385	452
5	59,466	413	108,637	543
6	47,255	328	100,961	505
7	58,550	407	148,960	745
8	74,787	519	398,237	1991
9	110,081	764	420,122	2101

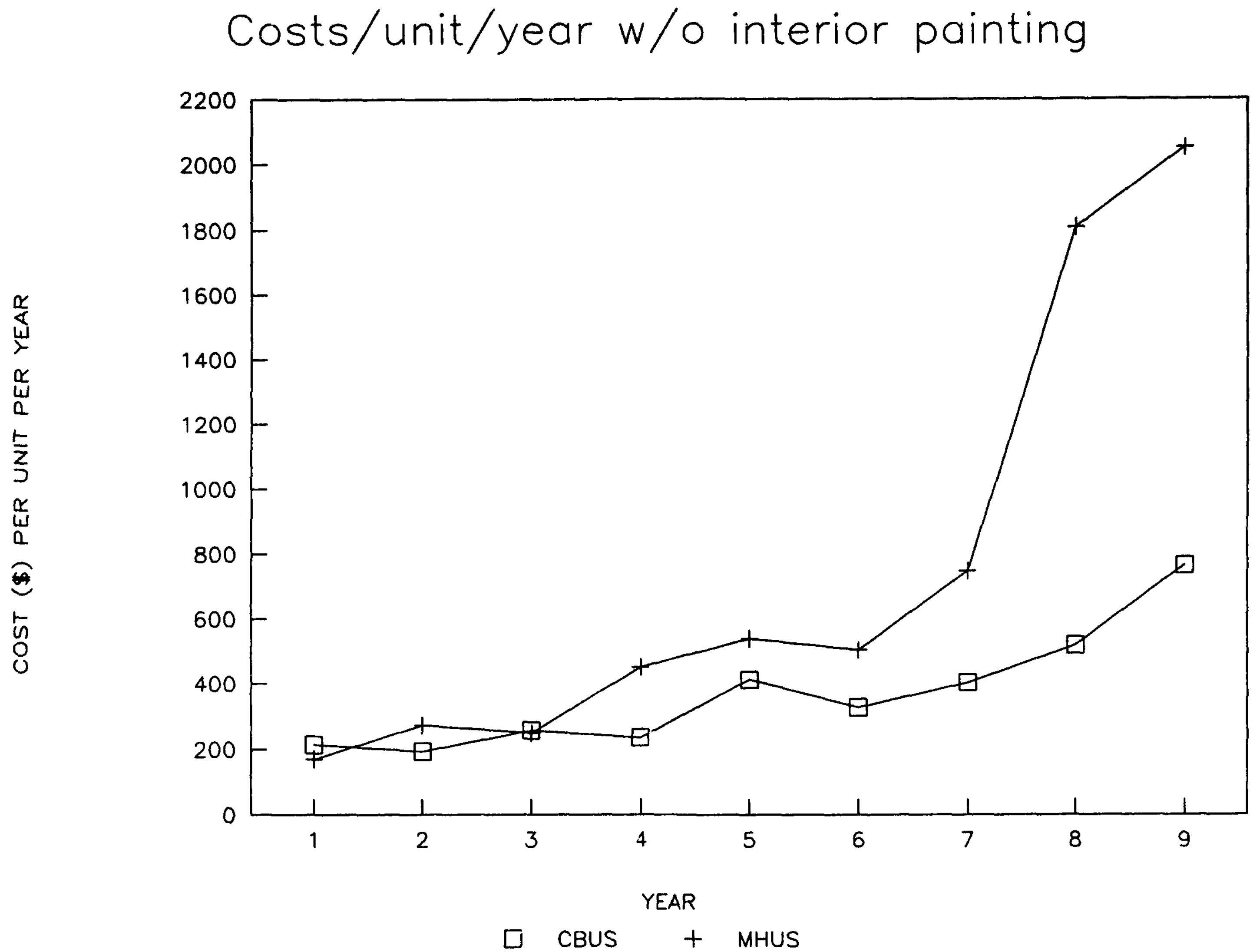


Figure 5. Costs per unit per year excluding interior painting costs.

Table 5

Unit Costs Excluding Certain Equipment Costs

Year	Total CBU ($)	Cost/ Unit ($)	Total MHU ($)	Cost/ Unit ($)
1	25,570	178	26,279	131
2	25,128	174	48,416	242
3	37,275	259	53,789	269
4	40,465	281	96,381	482
5	80,998	562	164,253	821
6	90,662	630	146,019	730
7	102,761	714	196,384	982
8	96,718	672	301,443	1507
9	157,430	1052	495,966	2480
9-Year Total	651,007	502	1,528,930	849

Table 6

Unit Costs Excluding Certain Equipment and Painting Costs

	Total Costs ($)		Cost/Unit ($)	
Year	CBU	MHU	CBU	MHU
1	24,966	25,965	173	130
2	23,894	43,929	166	219
3	30,245	40,048	210	200
4	29,079	71,995	202	360
5	51,278	83,768	356	419
6	41,217	71,255	286	356
7	49,420	127,146	343	636
8	67,136	359,630	466	1798
9	96,609	393,648	671	1968
9-Year Total	413,950	1,187,399	319	660

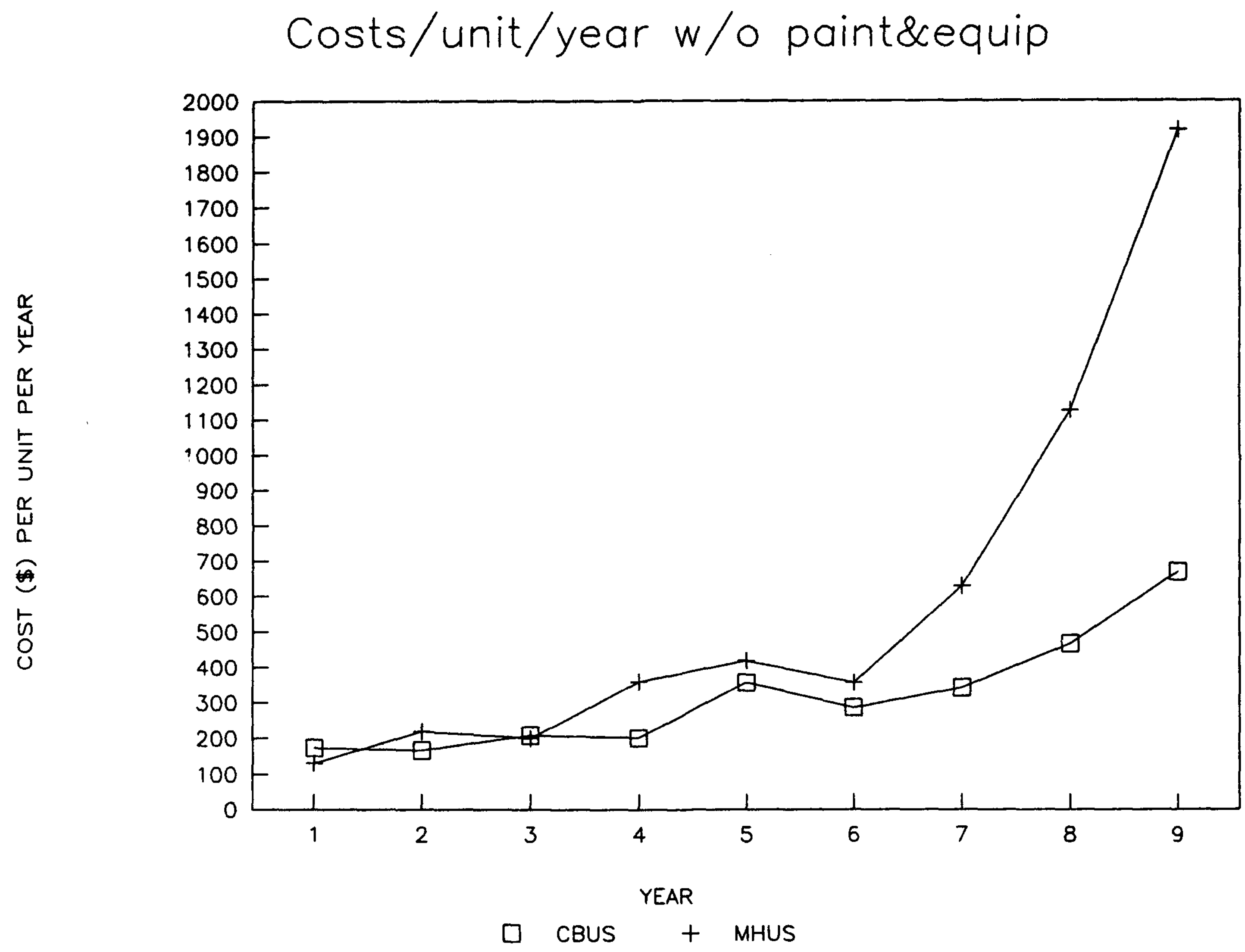


Figure 6. Costs per unit per year excluding certain equipment and painting costs.

Table 7

Maintenance Actions Performed and Costs Per Component

Component		Maintenance/Repair Actions				Cost ($)			
No.	Description	CBU		MHU		CBU		MHU	
		(N=17,192)*		(N=28,190)		(Total= 718,011)		(Total= 1,851,779	
101	Roofing surface	196	(1%)**	452	(2%)	20284	(3%)	347463	(19%)
103	Flashing, vents	34		16		745		567	
104	Gutters and downspouts	261	(2%)	319	(1%)	4175	(1%)	4877	
105	Other roof repairs	0		2		0		16	
201	Foundation and anchorage	3		2		24		24	
202	Structure	20		71		377		2706	
203	Insulation	3		0		42		0	
204	Masonry	10		19		240		1515	
205	Exterior siding	4		2		207		238	
206	Exterior doors and frames	666	(4%)	1077	(4%)	16857	(2%)	31843	(2%)
207	Storm and screen doors	823	(5%)	1189	(4%)	28713	(4%)	46519	(3%)
208	Windows and frames	179	(1%)	254	(1%)	4388	(1%)	7246	
209	Storm windows and screens	423	(2%)	405	(1%)	10509	(1%)	9034	
210	Exterior trim	0		2		0		26	
211	Porch/deck	5		5		102		159	
212	Interior drywall	292	(2%)	783	(3%)	8267	(1%)	51339	(3%)
213	Wall coverings and paneling	12		0		220		0	
214	Interior doors	1487	(9%)	1570	(6%)	29736	(4%)	26612	(1%)
215	Interior casework	55		93		968		2102	
216	Bathroom accessories	244	(1%)	271	(1%)	5139	(1%)	3839	
217	Kitchen accessories, cabinets	392	(2%)	580	(2%)	7021	(1%)	12529	(1%)
218	Drapery hardware	29		100		490		2131	
219	Other exterior/interior	302	(2%)	584	(2%)	13872	(2%)	56617	(3%)
220	Garage doors	692	(4%)	542	(2%)	18121	(3%)	12403	(1%)
301	Resilient flooring	54		338	(1%)	2068		14663	(1%)
302	Carpet and pad	17		83		939		5124	
304	Underlayment/substrate	2		6		13		70	
305	Other flooring	39		236	(1%)	6968	(1%)	32308	(2%)
401	Paint, walls and ceilings	332	(2%)	494	(2%)	234092	(33%)	426966	(23%)
402	Paint, trim	1		0		20		0	
403	Paint, touchup, interior	122	(1%)	314	(1%)	3234		17024	(1%)
404	Bathtub, shower caulking	291	(2%)	435	(2%)	4392	(1%)	6895	
405	Other interior painting	38		22		881		964	
501	Paint, exterior walls	3		3		92		45	
502	Paint, exterior doors, frames	5		5		138		125	
503	Paint, exterior trim	0		13		0		17767	(1%)
504	Exterior caulking	0		1		0		20	
506	Other exterior painting	2		3		44		75	

*N = Number of maintenance actions

**Percents are given for number maintenance actions and costs when the value is 1% or more of the total.

Table 7 (Cont'd)

Component		Maintenance/Repair Actions				Cost ($)			
No.	Description	CBU		MHU		CBU		MHU	
601	Heating plant, valve	102	(1%)	55		3617	(1%)	2855	
602	Motors, blowers, pumps	61		94		4331	(1%)	6494	
603	Ducts	1		36		15		2413	
604	Piping	7		6		190		293	
605	Diffusers, grills	14		65		325		920	
606	Insulation	0		2		0		61	
607	Heating controls	144	(1%)	101		6306	(1%)	4447	
608	Other heating	533	(3%)	846	(3%)	9824	(1%)	20227	(1%)
701	Cooling coils, compressor	48		52		9719	(2%)	3108	
702	A/C motors, blowers, pumps	98	(1%)	121		7314	(1%)	7151	
703	A/C piping, ducting	7		44		180		1419	
704	A/C refrigerant	394	(2%)	205	(1%)	13860	(2%)	7004	
705	A/C insulation	1		0		7		0	
706	A/C controls	103	(1%)	86		4514	(1%)	3349	
707	Other cooling	916	(5%)	1299	(5%)	32199	(4%)	45425	(2%)
801	Water heater	302	(2%)	664	(2%)	6884	(1%)	27369	(1%)
803	Piping, supply	168	(1%)	1359	(5%)	6860	(1%)	95333	(5%)
804	Faucets and shower heads	783	(5%)	1717	(6%)	22069	(3%)	46315	(3%)
805	Lavatories	479	(3%)	1071	(4%)	9697	(1%)	32113	(2%)
806	Water closets	829	(5%)	1301	(5%)	17700	(2%)	29484	(2%)
807	Bathtub/shower unit	171	(1%)	504	(2%)	3736		13320	(1%)
809	Other plumbing	222	(1%)	688	(2%)	5093	(1%)	27509	(1%)
901	Service entrance	2		2		65		188	
902	Panel box/circuit breakers	74		180	(1%)	3002		8134	
903	Branch circuits	19		21		532		1358	
904	Wall receptacles	347	(2%)	588	(2%)	7107	(1%)	15594	(1%)
905	Doorbells and chimes	2		1		46		4	
906	Light fixtures	1519	(9%)	1500	(5%)	29958	(4%)	36002	(2%)
907	Vents, fans	51		60		1162		1506	
908	Other electrical	48		56		1498		4120	
1001	Garbage disposal	429	(3%)	864	(3%)	8946	(1%)	21849	(1%)
1002	Dishwasher	383	(2%)	1091	(4%)	21590	(3%)	84083	(5%)
1003	Range	906	(5%)	1369	(5%)	21803	(3%)	33414	(2%)
1004	Range hood	108		111		2097		1980	
1005	Refrigerator	233	(1%)	583	(2%)	5395	(1%)	19545	(1%)
1006	Other equipment	158	(1%)	242	(1%)	1818		3549	
1201	Water supply	87	(1%)	196	(1%)	2115		7718	
1202	Gas supply	83		126		2386		3467	
1203	Electrical service	66		90		6098	(1%)	8800	
1204	Sanitary/sewer lines	5		4		657		191	
1205	Other utility service	0		1		0		8	
1300	Miscellaneous	251	(1%)	498	(2%)	13917	(2%)	81809	(4%)

Table 8

Maintenance Costs Per Component, Adjusted by Number of Units

Component		Costs ($)				
No.	Description	CBU	MHU	MHU Adjusted*	CBU/144**	MHU/200**
101	Roofing surface	20284	347463	250173	140.86	1737.32
103	Flashing, vents	745	567	408	5.17	2.84
104	Gutters and downspouts	4175	4877	3511	28.99	24.39
105	Other roof repairs	0	16	12	0.00	0.08
201	Foundations and anchorage	24	24	17	0.17	0.12
202	Structure	377	2706	1948	2.62	13.53
203	Insulation	42	0	0	0.29	0.00
204	Masonry	240	1515	1091	1.67	7.58
205	Exterior siding	207	238	171	1.44	1.19
206	Exterior doors and frames	16857	31843	22927	117.06	159.22
207	Storm and screen doors	28713	46519	33494	199.40	232.60
208	Windows and frames	4388	7246	5217	30.47	36.23
209	Storm windows and screens	10509	9034	6504	72.98	45.17
210	Exterior trim	0	26	19	0.00	0.13
211	Porch/deck	102	159	114	0.71	0.80
212	Interior drywall	8267	51339	36964	57.41	256.70
213	Wall coverings and paneling	220	0	0	1.53	0.00
214	Interior doors	29736	26612	19161	206.50	133.06
215	Interior casework	968	2102	1513	6.72	10.51
216	Bathroom accessories	5139	3839	2764	35.69	19.20
217	Kitchen accessories, cabinets	7021	12529	9021	48.76	62.65
218	Drapery hardware	490	2131	1534	3.40	10.66
219	Other exterior/interior	13872	56617	40764	96.33	283.09
220	Garage doors	18121	12403	8930	125.84	62.02
301	Resilient flooring	2068	14663	10557	14.67	73.32
302	Carpet and pad	939	5124	3689	6.52	25.62
304	Underlayment/substrate	13	70	50	0.09	0.35
305	Other flooring	6968	32308	23262	48.39	161.54
401	Paint, walls and ceilings	234092	426966	307416	1625.64	2134.83
402	Paint, trim	20	0	0	0.14	0.00
403	Paint, touchup, interior	3234	17024	12257	22.46	85.12
404	Bathtub, shower caulking	4392	6895	4964	30.50	34.48
405	Other interior painting	881	964	694	6.12	4.82
501	Paint, exterior walls	92	45	32	0.64	0.23
502	Paint, exterior doors, frames	138	125	90	0.96	0.63
503	Paint, exterior trim	0	17767	12791	0.00	88.84
504	Exterior caulking	0	20	14	0.00	0.10
506	Other exterior painting	44	75	54	0.31	0.38
601	Heating plant, valve	3617	2855	2056	25.12	14.28
602	Motors, blowers, pumps	4331	6494	4676	30.08	32.47

*The MHU column adjusted by multiplying by 0.72.

**These are costs per unit for the 9 years.

Table 8 (Cont'd)

Component		Costs ($)				
No.	Description	CBU	MHU	MHU Adjusted*	CBU/144**	MHU/200**
603	Ducts	15	2413	1737	0.10	12.07
604	Piping	190	293	211	1.32	1.47
605	Diffusers, grills	325	920	662	2.26	4.60
606	Insulation	0	61	44	0	0.31
607	Heating controls	6306	4447	3202	43.79	22.24
608	Other heating	9824	20227	14563	68.22	101.14
701	Cooling coils, compressor	9719	3108	2238	67.49	15.54
702	A/C motors, blowers, pumps	7314	7151	5149	50.79	35.76
703	A/C piping, ducts	180	1419	1022	1.25	7.10
704	A/C refrigerant	13860	7004	5043	96.25	35.02
705	A/C insulation	7	0	0	0.05	0.00
706	A/C controls	4514	3349	2411	31.35	16.75
707	Other cooling	32199	45425	32706	223.60	227.13
801	Water heater	6884	27369	19706	47.81	136.85
803	Piping, supply	6860	95333	68640	47.64	476.67
804	Faucets and shower heads	22069	46315	33347	153.26	231.58
805	Lavatories	9697	32113	23121	67.34	160.57
806	Water closets	17700*	29484	21228	122.92	147.42
807	Bathtub/shower unit	3736	13320	9590	25.94	66.60
809	Other plumbing	5093	27509	19806	35.37	137.55
901	Service entrance	65	188	135	0.45	0.94
902	Panel box/circuit breakers	3002	8134	5856	20.85	40.67
903	Branch circuits	532	1358	978	3.69	6.79
904	Wall receptacles	7107	15594	11228	49.35	77.97
905	Doorbells and chimes	46	4	3	0.32	0.02
906	Light fixtures	29958	36002	25921	208.04	180.01
907	Vents, fans	1162	1506	1084	8.07	7.53
908	Other electrical	1498	4120	2966	10.40	20.60
1001	Garbage disposal	8946	21849	15731	62.13	109.25
1002	Dishwasher	21590	84083	60540	149.93	420.42
1003	Range	21803	33414	16858	151.41	117.07
1004	Range hood	2097	1980	1426	14.56	9.90
1005	Refrigerator	5395	19545	14072	37.47	97.73
1006	Other equipment	1818	3549	2555	12.63	17.75
1201	Water supply	2115	7718	5557	14.69	38.59
1202	Gas supply	2386	3467	2496	16.57	17.34
1203	Electrical service	6098	8800	6336	42.35	44.00
1204	Sanitary/sewer lines	657	191	138	4.56	0.96
1205	Other utility service	0	8	6	0.00	0.04
1300	Miscellaneous	13917	81809	58902	96.65	409.05
	Totals	718,011	1,851,779	1,333,281		

Note the $17,767 cost for exterior-trim painting of MHUs and $0 for CBUs (component no. 503). The exterior trim was to be painted on a cyclic basis. The CBU cycle in 1988 was deferred. Both CBU and MHU exterior-trim painting for 1989-93 was deferred.

Table 9 groups the Table 10 data into the 12 major building component codes (Appendix C). Although the 0201-0220 structure is a high cost item, Table 8 shows most of these costs are related to doors and windows, and some of the damage to these items was caused by the occupant. Note the plumbing costs for the MHUs is 2.7 times that for the CBUs

Roofing Replacement/Repairs

Several contracts were executed late in year 8 and in year 9 to reroof the MHUs. A total of $305,811 was expended. This is one reason the MHU cost per unit is so high in years 8 and 9.

Water Piping Problems

The manufacturer used polybutylene piping in the CBU units. The piping was installed in the building modules at the plant in Southern California and many connections made after the modules were assembled at Fort Irwin (after 200 miles of transportation).

These manufactured apartments are two-story fourplexes; two units above two units. Piping runs through walls, the ceiling of the first floor units (i.e., the floor of the upper units) and under the first floor units in the crawl space.

There have been many leaks in the piping with several major breaks in a "tee" joint in the ceiling of the first floor units of the MHUs. A detailed analysis of plumbing service orders shows a higher cost for MHUs for the category leaking or broken piping. Costs for each of the 9 years are shown in Table 10.

Most leaks are breaks of the hard plastic tees and valves, usually under the crimped metal band. The problem is so bad that all piping is to be replaced. A contract was executed for replacement in one building to develop the methods and to get a better idea of the cost.

This is not a new problem in the plastic pipe industry. A "60 Minutes" television program shown in December 1990, described many problems in the Southwest with such materials. The companies paid required repairs because the plastic material itself was defective.

Summary of M&R Costs

In year 9, the MHUs cost $2613 - $1147= $1466/unit more (statistically significant) than the CBUs overall and $1968 - $671 = $1297 more excluding certain equipment and painting costs. About $167 of these differences was due to water piping alone. The $1466 - $167 = $1299 difference for overall M&R costs in year 9 is significant.

Figure 7 shows the number of units incurring costs in various ranges. Note that MHUs dominate the higher costs ranges (above $2000) i.e., in year 9, many more MHUs had M&R costs above $2000 than did CBUs.

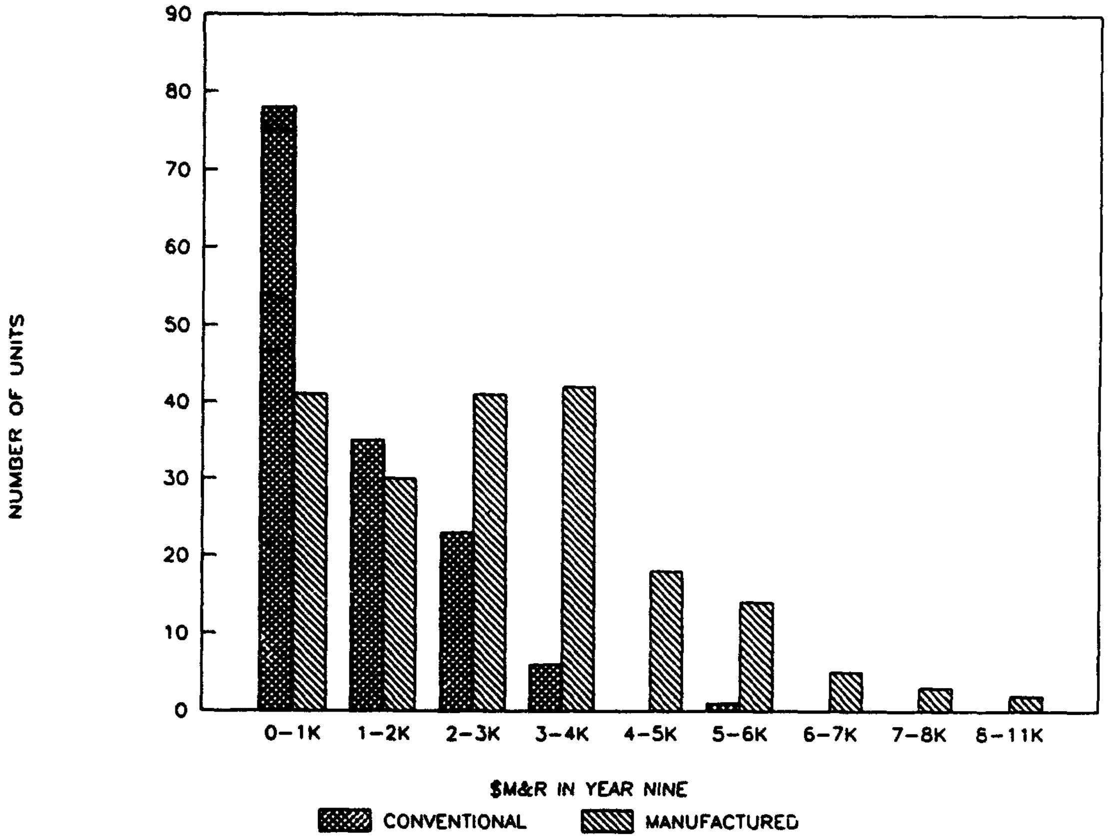


Figure 7. Histogram of year 9 M&R costs.

Table 9

Maintenance Actions Performed and Costs for Component Group, 9-Year Summary

Component Group	Description	Maintenance/Repair Actions: CBU (N=17,192)		Maintenance/Repair Actions: MHU (N=28,190)		Cost ($): CBU (Total = 718,011)		Cost ($): MHU (Total = 1,851,779)		MHU Adjusted (Total = 1,333,281)
0101-0105	Roofing	491	(3%)	789	(3%)	25,205	(4%)	352,924	(19%)	254,105
0201-0220	Structure	5,641	(33%)	7,549	(27%)	145,295	(20%)	266,882	(14%)	192,155
0301-0305	Floor coverings	112	(1%)	663	(2%)	9,988	(1%)	52,164	(3%)	37,558
0401-0405	Interior painting	784	(5%)	1,265	(4%)	242,620	(34%)	451,848	(24%)	325,331
0501-0506	Exterior painting	10	(0%)	25	(0%)	274	(0%)	18,032	(1%)	12,983
0601-0608	Heating	862	(5%)	1205	(4%)	24,607	(3%)	37,711	(2%)	27,152
0701-0707	Air conditioning	1,567	(9%)	1,807	(6%)	67,793	(9%)	67,456	(4%)	48,568
0801-0809	Plumbing	2,954	(17%)	7,304	(26%)	72,038	(10%)	271,442	(15%)	195,438
0901-0908	Electrical	2,062	(12%)	2,408	(9%)	43,360	(6%)	66,907	(4%)	48,173
1001-1006	Equipment	2,217	(13%)	4,260	(15%)	61,649	(9%)	164,421	(9%)	118,383
1201-1205	Utility service	241	(1%)	417	(1%)	11,256	(2%)	20,183	(1%)	14,532
1300	Miscellaneous	251	(1%)	498	(2%)	13,917	(2%)	81,809	(4%)	58,902

Table 10

Water Piping Costs

Year	CBUs ($)	MHUs ($)
1	776	1,134
2	473	2,524
3	408	758
4	408	1,769
5	108	2,462
6	487	4,870
7	557	12,458
8	1,665	33,332
9	1,978	36,068
Total	6,860	95,377

The two major deficiencies found in the MHUs to date were the improperly installed hingeable eaves and the water piping. Both of these were caused by improper design (eaves), improper material specification, and poor quality workmanship (water piping). Neither of these problems is considered a defect due to the type of construction—manufactured. Although not due to type of construction (in this instance at Fort Irwin), the project will cost the Army an additional $334,600 (eaves repair) + $1,225,000 (piping replacement) = $1,559,600 ($7800 per unit), which would not have occurred if the same conventional construction had been used as in the 144 units.

7 ENERGY COSTS

Comparisons of gas and electricity consumption began in May 1984, since most MHUs were not occupied before then.

Electricity Consumption

The average quarterly electric usage (in kWh) per housing unit is shown in Table 11 and Figure 8. The MHUs had higher average consumptions than the CBUs in 16 of the 36 quarters and higher in 8 of the 9 summer quarters, Jun-Aug. For the entire 108-month data collection period, an MHU used an average total of 83,650 kWh, while a CBU used an average total of 82,803 kWh. This was a difference of 847 kWh ÷ 108 months = 7.84 kWh/month. At the June 1993 rate of $0.0991/kWh, an MHU cost $0.78 more than a CBU for electricity per month. Average yearly electricity usage is shown in Figure 9.

Gas Consumption

The type of fuel used was liquid propane (LP). LP is delivered to a central facility on post and is converted to gas and distributed to housing units through underground pipes. The average quarterly usage (cu ft) per housing unit is shown in Table 12 and Figure 10.

For the 108-month period, an MHU used an average total of 172,220 cu ft while a CBU used an average total of 162,650 cu ft. The MHUs had higher average consumptions in 29 of the quarters, always higher in the winter, Dec-Feb, and in seven of the nine spring quarters, Mar-May. This is a difference of 9,570 cu ft ÷ 108 months = 89 cu ft/month. At the June 1993 cost of $0.01303/cu ft, an MHU cost $1.16 more than a CBU for gas per month. Average yearly gas usage is shown in Figure 11.

Statistical Analysis of Consumption

One-way analysis of variance tests showed significant differences among the 9 years of data for gas and electricity consumption for each of the types of construction.

T-tests were performed comparing the construction types for each year for both gas and electricity consumption. Results are shown below:

Average Consumptions for Each Year

		1	2	3	4	5	6	7	8	9
Electricity	MHUS	8613	9027	8895	8959	9658	9223	9255	9906	9267
(kWh)	CBUS	8195	8757	9093	9255	9654	9358	9054	10251	10033
Gas	MHUS	21340*	18020*	19320	19890	19060	18320*	20140*	17780	18350
(Cu Ft)	CBUS	19200	16810	19010	19360	18170	16650	17480	16050	18190

An asterisk (*) means there is a statistically significant difference between the types of construction for average unit consumption for a year. (Tests were at the 99% confidence level.) Note there were no significant differences for electricity consumption.

Total Energy Consumption

The total energy consumption for the housing units is shown in Table 13. It was calculated by converting the gas and electricity consumption data to MBTU/KSF. (One cubic foot of propane gas = 2618.5 BTU and one kWh of electricity = 3413 BTU.) The area of the housing units is approximately 950 sq ft, so a multiplier of 1000/950 = 1.053 was used to convert usage to kilowatts per square foot.

Cost Comparison Summary

The averages for dwelling unit energy consumption and cost for the 9-year period (May 1984 to April 1993) are given in Table 14. The MHUs on the average have cost $23 more (2%) per year for gas and electricity than the CBUs.

Meter Problems

Many meters have become defective over the past 9 years. For the CBUs, 49 electric and 9 gas meters have failed while for the MHUs, 20 electric and 5 gas have failed.

Comments

The data in Chapter 5 (better air tightness and higher furnace efficiencies for the MHUs) would indicate the MHUs should use less energy than the CBUs. However, this is offset by the higher overall heat loss of the MHUs. Detailed energy simulations (performed using the Building Loads Analysis and System Thermodynamics* program) indicate two design/construction features that cause the higher wall-heat loss: the MHUs have more window/door glass area; and the MHUs have single-pane glass while the CBUs have thermal-pane. Additionally, the CBUs were built on concrete slabs while the MHUs have crawl spaces, which are less energy efficient.

*The Building Loads Analysis and System Thermodynamics (BLAST) program was developed by USACERL and is used throughout the Department of Defense for military construction projects.

Table 11

Average Quarterly Electricity Consumption (kWh) Per Housing Unit

	1984 Jun-Aug	Sep-Nov	1984-5 Dec-Feb	1985 Mar-May	Jun-Aug	Sep-Nov	1985-6 Dec-Feb	1986 Mar-May
MHU	3492	2005	1399	1737	4053	1743	1470	1763
CBU	3263	1925	1353	1655	3752	1857	1410	1738

	1986 Jun-Aug	Sep-Nov	1986-7 Dec-Feb	1987 Mar-May	Jun-Aug	Sep-Nov	1987-8 Dec-Feb	1988 Mar-May
MHU	3951	1778	1500	1725	3644	2191	1483	1702
CBU	3683	1934	1630	1813	3550	2411	1494	1768

	1988 Jun-Aug	Sep-Nov	1988-9 Dec-Feb	1989 Mar-May	Jun-Aug	Sep-Nov	1989-90 Dec-Feb	1990 Mar-May
MHU	3738	2366	1550	1996	3892	2192	1523	1750
CBU	3513	2445	1610	2024	3634	2180	1478	1823

	1990 Jun-Aug	Sep-Nov	1990-1 Dec-Feb	1991 Mar-May	Jun-Aug	Sep-Nov	1991-92 Dec-Feb	1992 Mar-May
MHU	3796	2341	1467	1624	3620	2641	1615	2037
CBU	3406	2252	1600	1730	3616	2650	1680	2237

	1992 Jun-Aug	Sep-Nov	1992-3 Dec-Feb	1993 Mar-May
MHU	3900	2286	1373	1613
CBU	3933	2322	1684	1962

Table 12

Average Quarterly Gas Consumption (cu ft) Per Housing Unit

	1984 Jun-Aug	Sep-Nov	1984-5 Dec-Feb	1985 Mar-May	Jun-Aug	Sep-Nov	1985-6 Dec-Feb	1986 Mar-May
MHU	1890	4400	10050	5130	1890	4440	7670	4020
CBU	1780	3730	9200	4500	1840	3970	7080	3950

	1986 Jun-Aug	Sep-Nov	1986-7 Dec-Feb	1987 Mar-May	Jun-Aug	Sep-Nov	1987-8 Dec-Feb	1988 Mar-May
MHU	1800	3810	9340	4390	1910	3300	9930	4740
CBU	2130	3520	9070	4500	2160	3430	9500	4460

	1988 Jun-Aug	Sep-Nov	1988-9 Dec-Feb	1989 Mar-May	Jun-Aug	Sep-Nov	1989-90 Dec-Feb	1990 Mar-May
MHU	1880	3490	10000	3700	1920	3400	9080	3910
CBU	1960	3250	9400	3550	1960	3140	8160	3390

	1990 Jun-Aug	Sep-Nov	1990-1 Dec-Feb	1991 Mar-May	Jun-Aug	Sep-Nov	1991-92 Dec-Feb	1992 Mar-May
MHU	1850	3340	9080	5950	1810	3190	8690	4060
CBU	1790	2920	7810	4950	1730	2780	7590	3950

	1992 Jun-Aug	Sep-Nov	1992-3 Dec-Feb	1993 Mar-May
MHU	1770	3470	8990	3710
CBU	1720	3240	8870	4250

Table 13

Total Energy Consumption

	MHU		CBU	
	Gas (cu ft)	Electricity (kWh)	Gas (cu ft)	Electricity (kWh)
9 year total	172,220	83,650	162,650	82,803
Yearly average	19,136	9,294	18,072	9,200
MBTU/year	50.11	31.72	47.32	31.40
Total energy per year	81.83 MBTU		78.72 MBTU	
Conversion to MBTU/ksq ft	86.17 MBTU/yr		82.89 MBTU/yr	

(MBTU = million British thermal units, CF = cubic feet)

Table 14

Nine-Year Summary of Energy Consumption

	MHU		CBU	
	Gas (cu ft)	Electricity (kWh)	Gas (cu ft)	Electricity (kWh)
Average Consumption/Year Per Housing Unit	19,136	9,294	18,072	9,200
Average Cost/Year Per Housing Unit	$249	$921	$235	$912
Total Cost/Year	$1170		$1147	

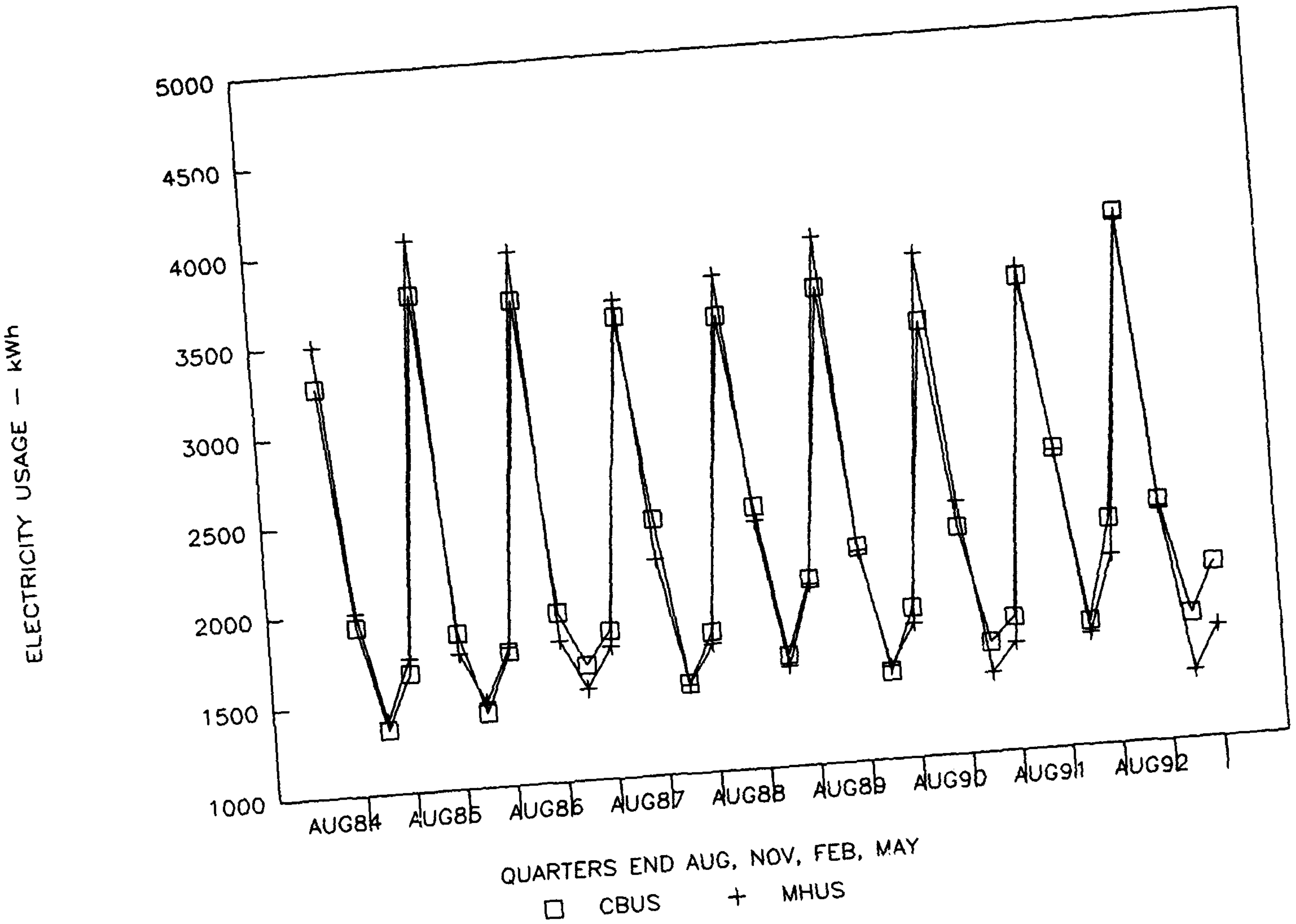


Figure 8. Quarterly electricity consumption.

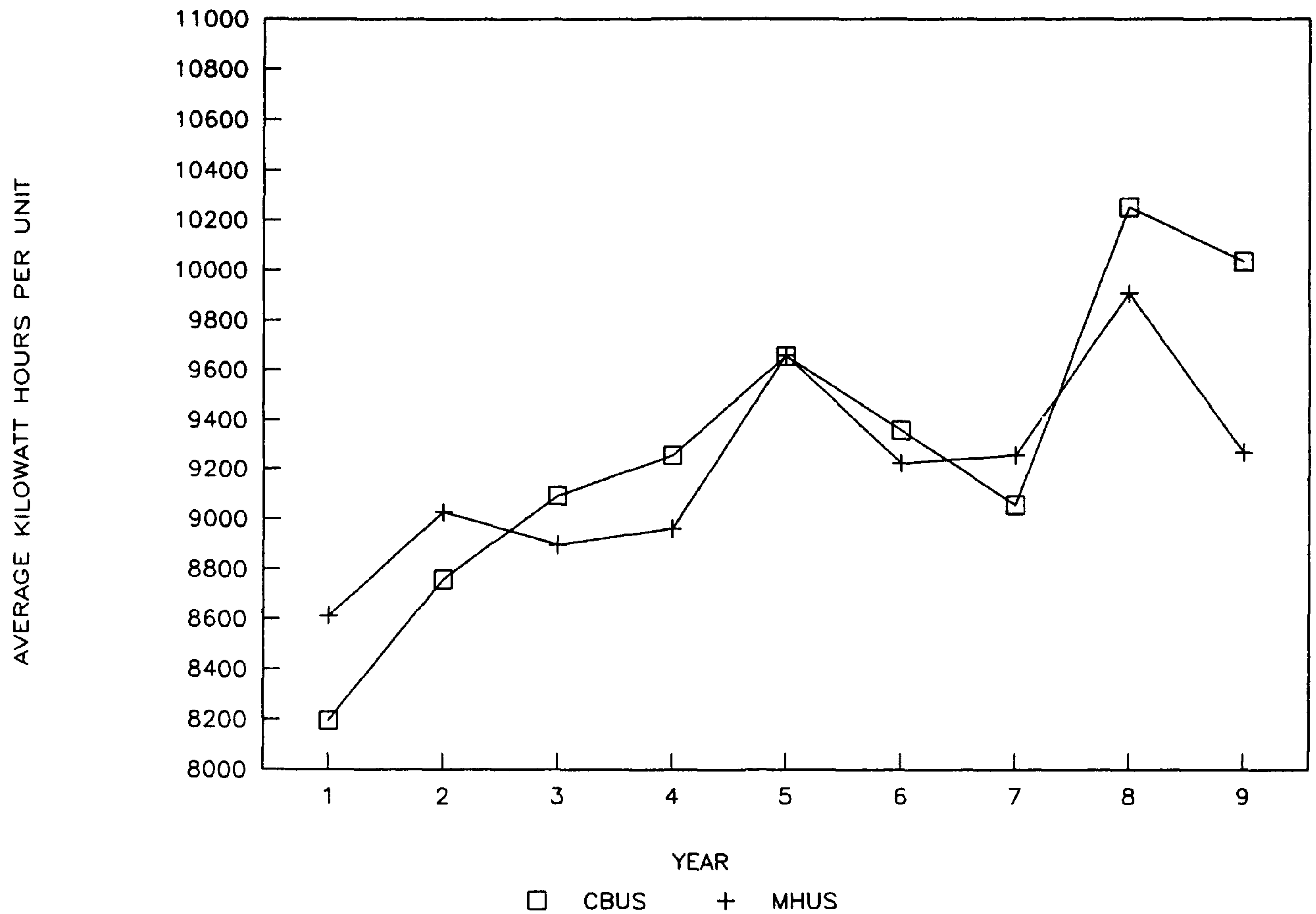


Figure 9. Yearly electricity consumption.

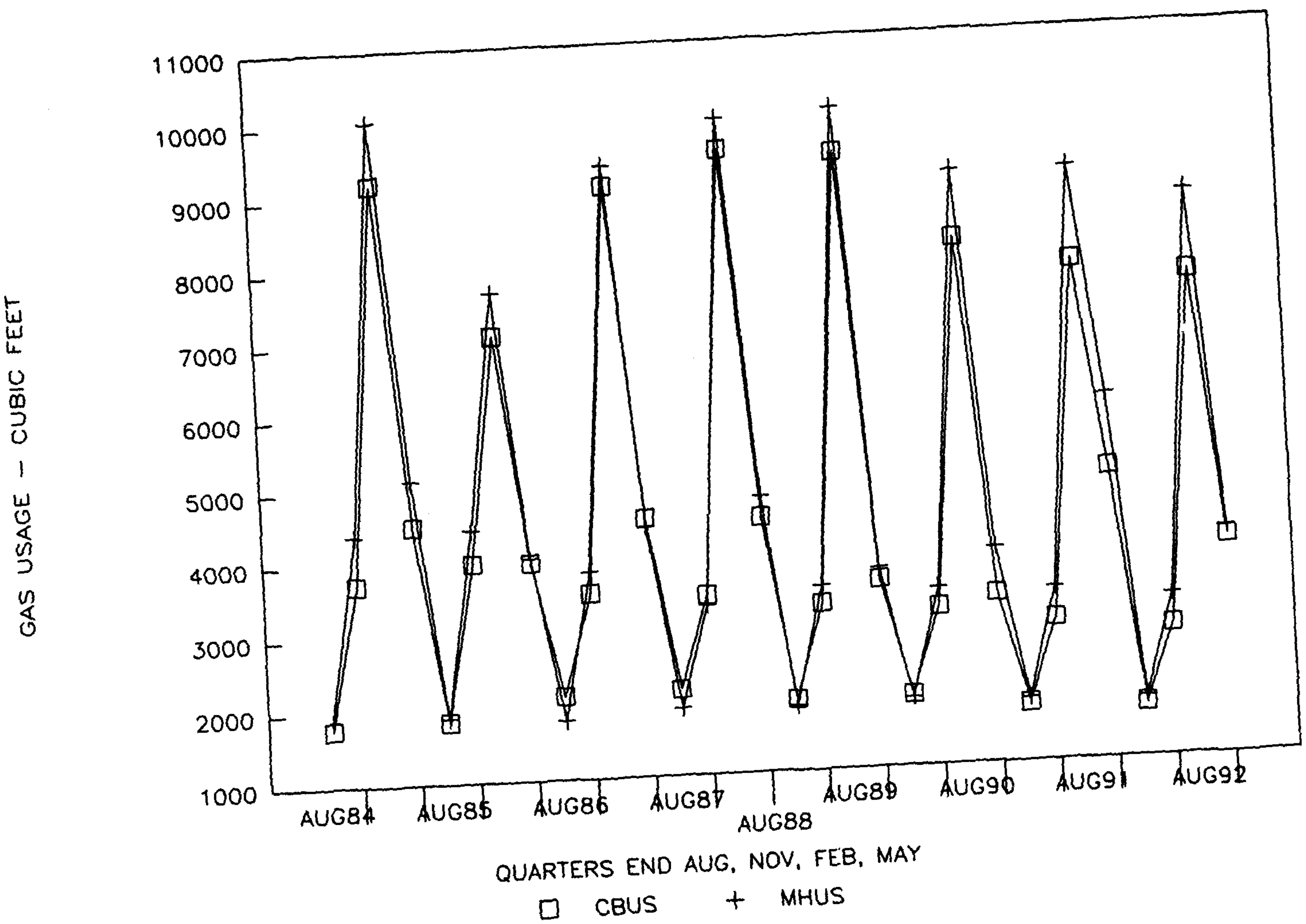


Figure 10. Quarterly gas consumption.

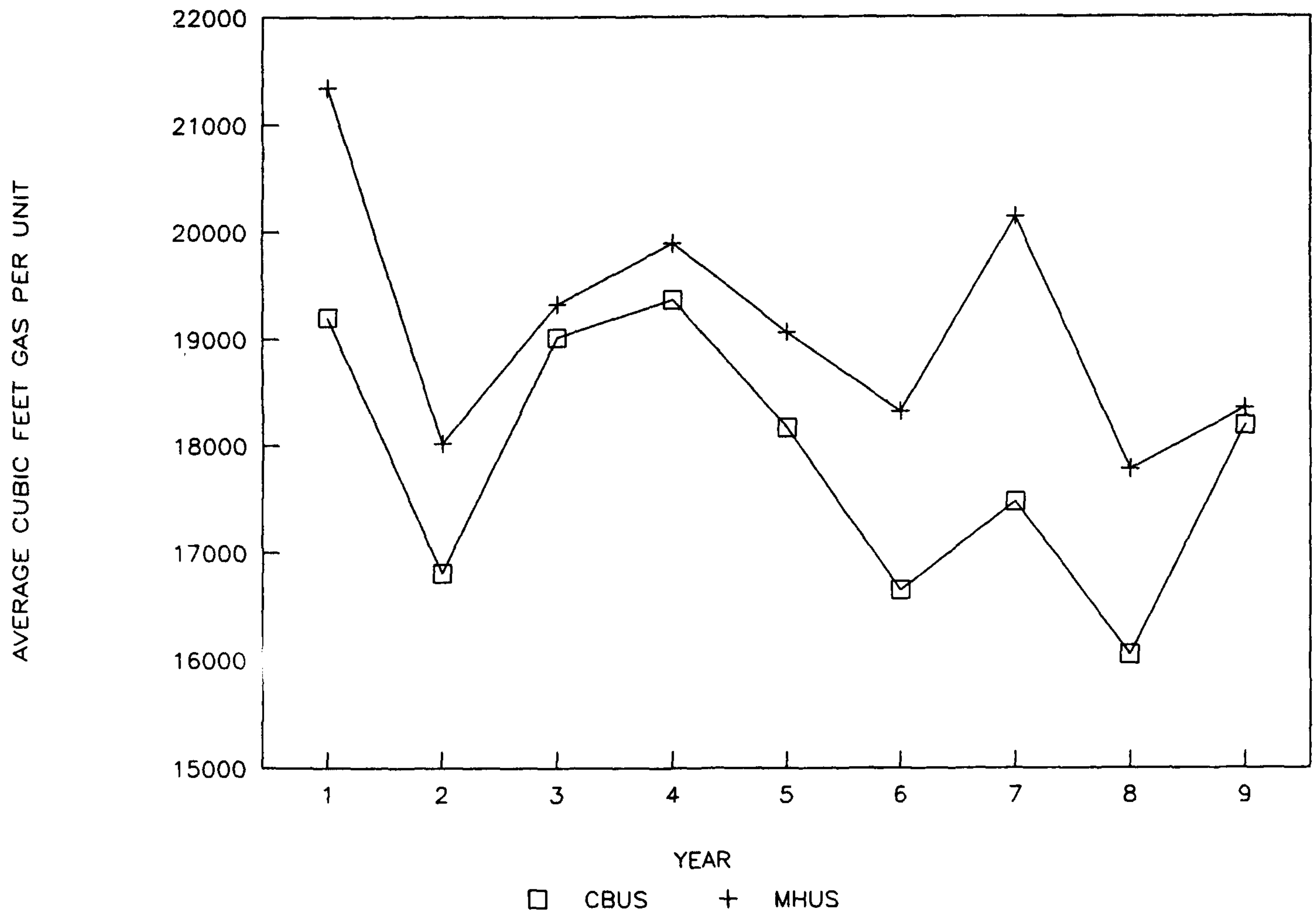


Figure 11. Yearly gas consumption.

8 CONCLUSIONS AND RECOMMENDATIONS

Maintenance Costs

After 9 years' occupancy, there is a significant difference in maintenance costs between the two types of units. For all 9 years, the MHUs cost $347 more per unit per year for maintenance (ignoring equipment costs, such as ranges and dishwashers). This is a 69 percent difference in costs ($849/year for MHU vs $502/year for CBU, Table 5). For year 9, the difference is $278 or 136 percent ($2480 for MHU vs $1052 for CBU).

Energy Costs

MHUs cost more than CBUs for energy used—$23 more per unit per year for gas and electricity.

Water Piping

The MHU water piping is being replaced. Piping failures are not only significantly increasing the cost, but also are affecting the morale of families in units with major problems. There is a very significant difference to the government in costs between the two types of construction due to this problem.

It is recommended data collection continue for 1 more year.

APPENDIX A: Description of the MHU Construction Process

The MHUs were not typical of manufactured housing in that the manufacturer was not allowed to design the housing. The contractor was given designs based on the fourplexes being built using conventional construction methods and was required to manufacture accordingly. Thus, it is possible that given the opportunity to both design and manufacture, the final structure might be somewhat different and less costly.

The concept used was to manufacture complete modules in the factory, which could be transported (about 200 miles from the factory in the Los Angeles area to Fort Irwin) and assembled on site. Thus, the process involved several steps: manufacture of complete modules (electrical, plumbing, HVAC, etc., included at the plant); construction of perimeter footings at the site; transportation of modules to the site; assembly of the modules into fourplexes using a crane; joining modules together including connection of piping and electrical wiring; application of stucco exterior finish; roofing at the module joints and securing of eaves; and on-site construction of the garages. On-site construction was limited by contract to foundations, utilities, slabs, garages, exterior finishes, final painting, exterior stairways and balconies. Figures A1 through A6 show factory work, modules on trucks, crane assembly and a completed fourplex without stucco and garages.

The eaves were attached using flat metal straps and folded onto the roof for transportation (this decreased the width for highway transportation). Upon assembly at the site, the eaves were folded down and secured with only a few nails. This was a defect in the design/construction, as the eaves began to loosen; one fell to the ground. All eaves were then permanently secured at a cost of over $300,000 ($6000 per building).

The MHUs are essentially the same as the CBUs; floor plans of the two types are very similar. Figures A7 through A10 show sample floor plans for the MHUs and the CBUs.

Figure A1. Construction in the factory.

Figure A2. Two modules loaded on truck.

Figure A3. Module being set in place by crane.

Figure A4. Near completion of one building.

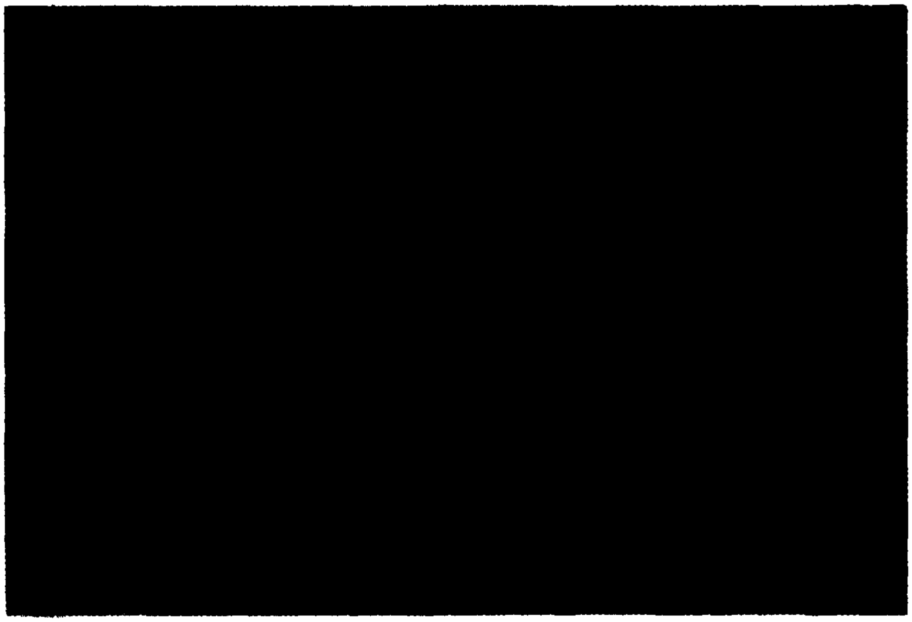


Figure A5. Completed assembly of modules.

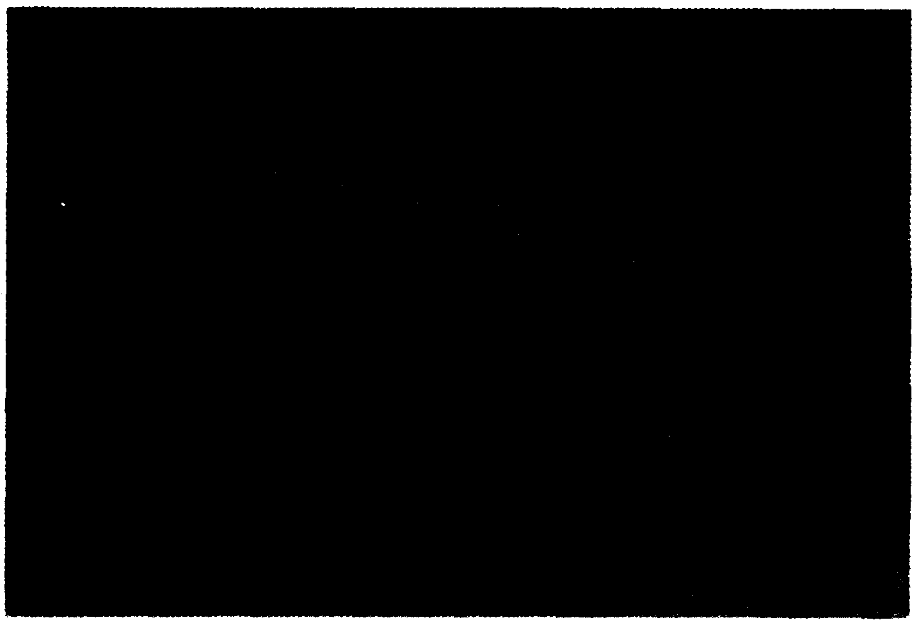


Figure A6. Overview of buildings without garages.

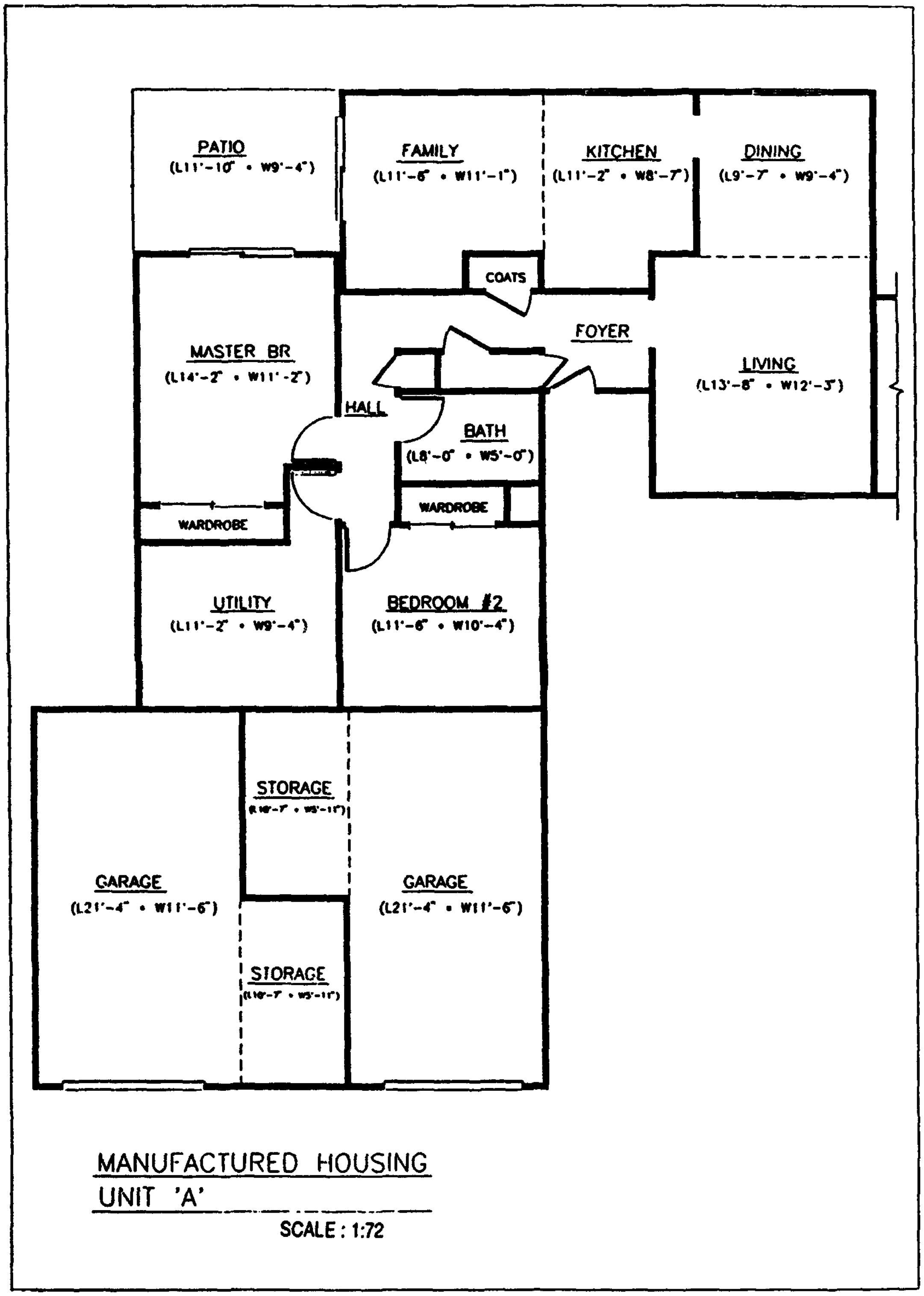


Figure A7. Floor plan for first floor MHU, Type A.

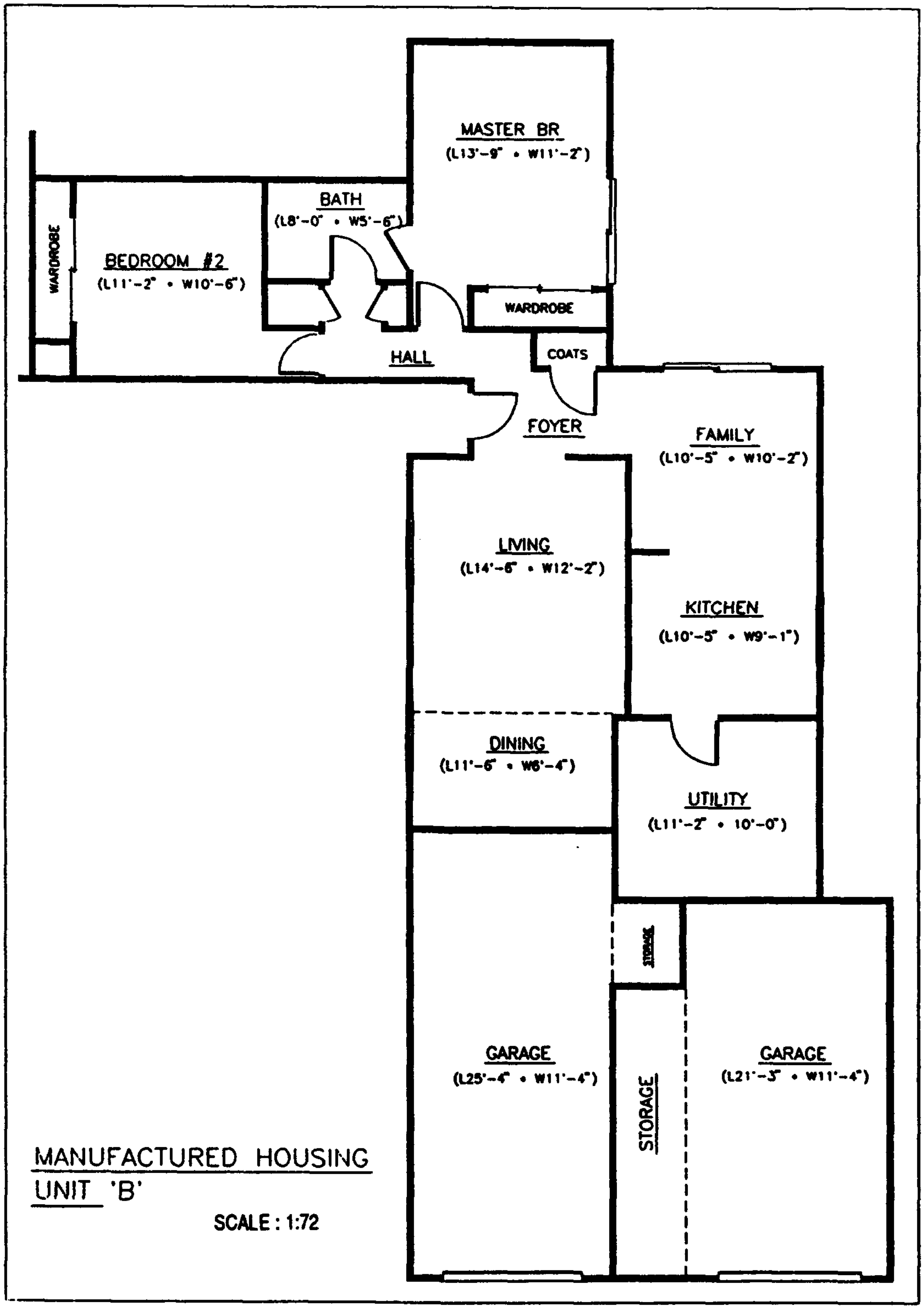


Figure A8. Floor plan for first floor MHU, Type B.

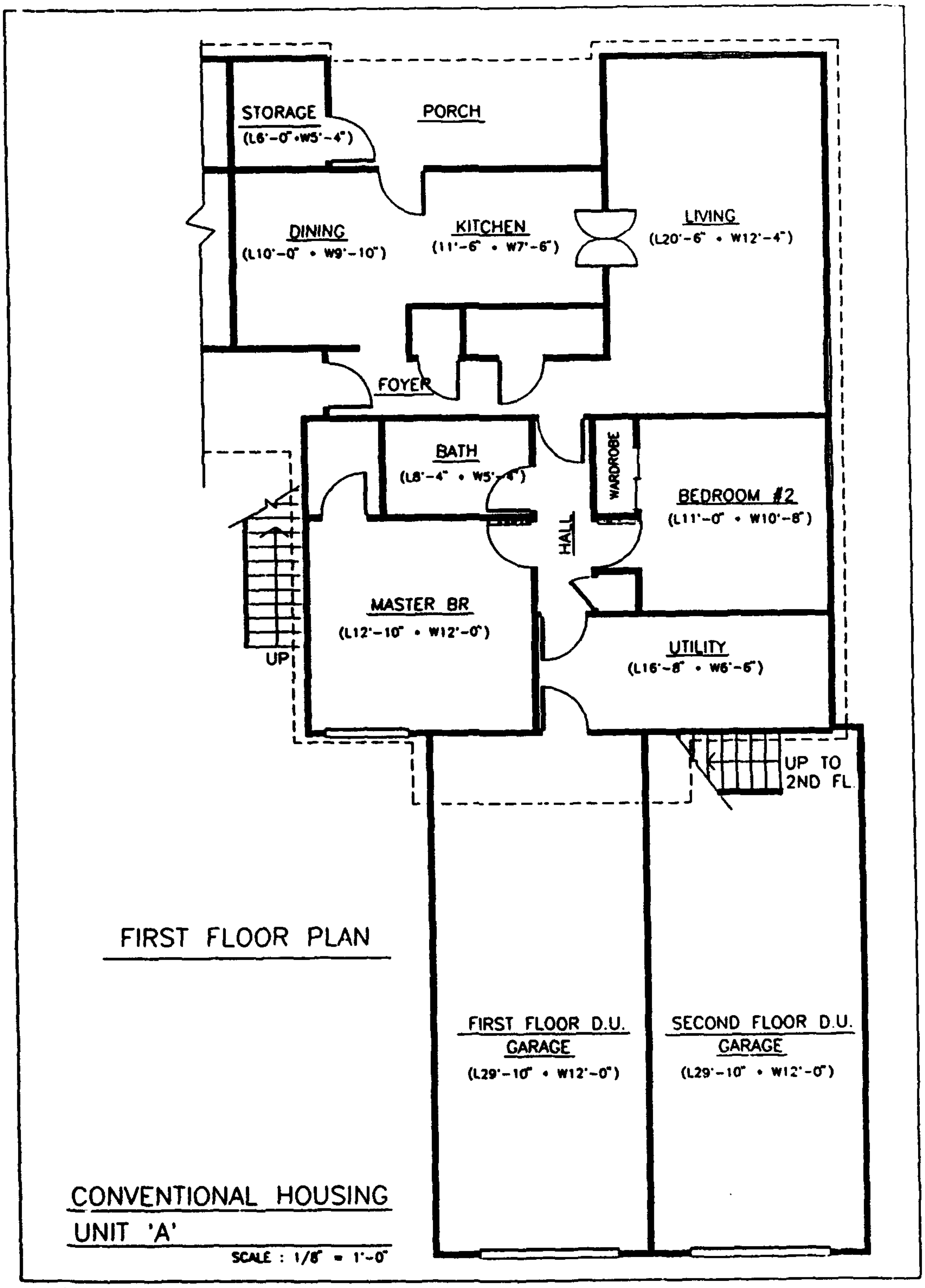


Figure A9. Floor plan for first floor CBU, Type A.

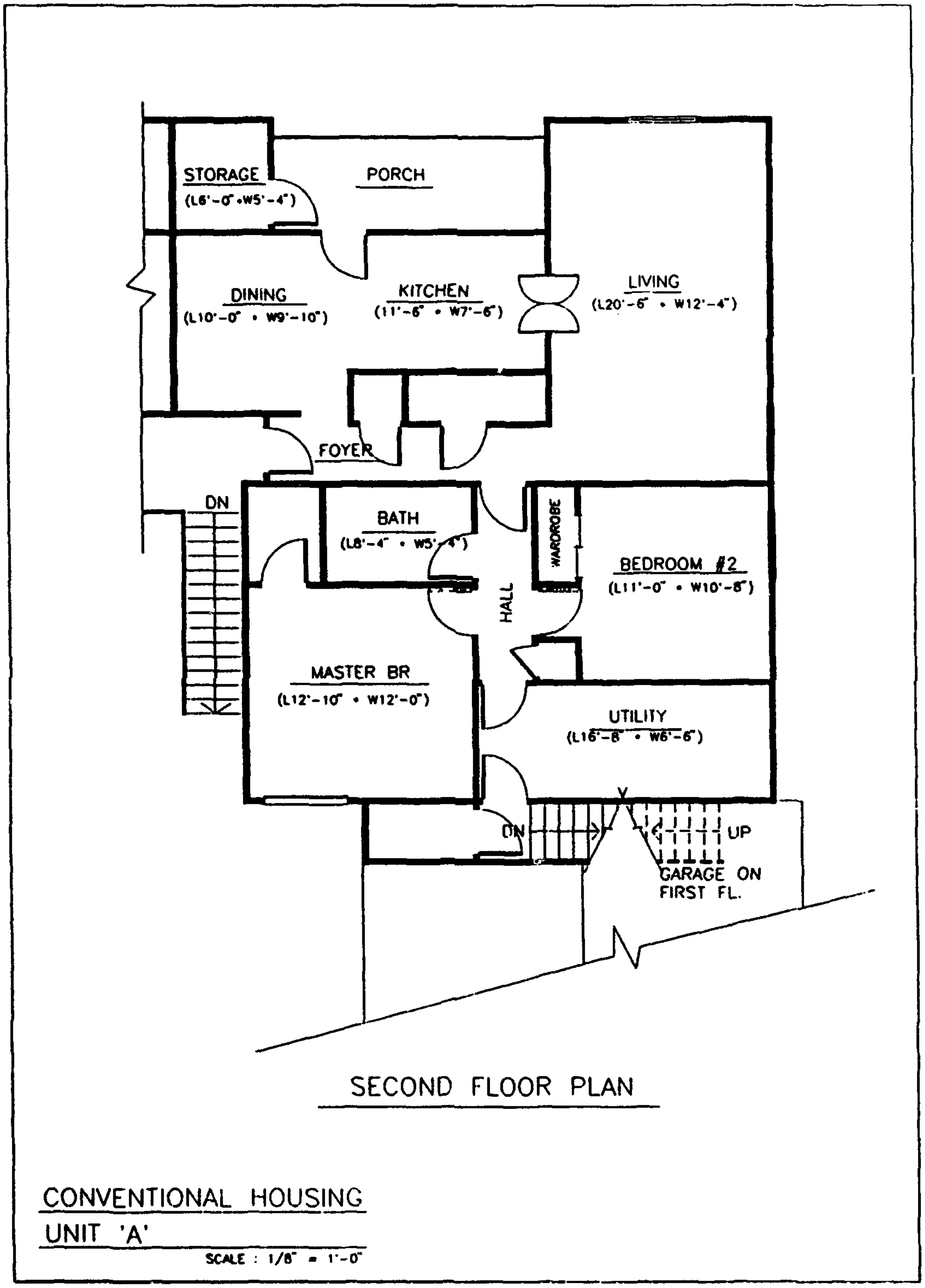


Figure A10. Floor plan for second floor CBU, Type A.

APPENDIX B: List of Housing Units

Conventionally Built

3680 A-F	3705 A-E	3727 A-E
3681 A-D	3712 A-F	3731 A-D
3684 A-D	3715 A-F	3732 A-F
3685 A-F	3720 A-F	3738 A-F
3690 A-F	3721 A-E	3742 A-D
3691 A-D	3722 A-E	3743 A-F
3693 A-F	3723 A-E	3745 A-F
3694 A-D	3724 A-D	3747 A-D
3695 A-D	3725 A-E	3750 A-F
3700 A-F		

Manufactured (Each with four apartments, A-D)

3800	3821	3841
3801	3822	3842
3802	3823	3843
3803	3824	3844
3804	3825	3845
3805	3826	3846
3806	3827	3848
3807	3828	3850
3809	3829	3851
3811	3831	3852
3812	3832	3853
3813	3833	3854
3814	3834	3855
3815	3835	3856
3816	3837	3857
3818	3839	3858
3820	3840	

APPENDIX C: Building Component/Subcomponent Codes

01 Roofing

0101	Roofing surface
0102	Fasteners
0103	Flashing, vents, protrusions
0104	Gutter and downspouts
0105	Other roof repairs

02 Structure

0201	Foundation and anchorage
0202	Structure, incl. framing and sheathing, stairs, cracked wall
0203	Insulation and moisture protection
0204	Masonry
0205	Exterior siding, incl. skirting
0206	Exterior doors and frames, incl. hardware and weatherstripping
0207	Storm and screen doors
0208	Window and frames, incl. hardware and weatherstripping
0209	Storm windows and screens
0210	Exterior trim
0211	Porch/deck construction
0212	Interior drywall, incl. fasteners and accessories
0213	Wall coverings and paneling
0214	Interior doors, frames, and hardware, incl. bifold and sliding
0215	Interior casework and finish carpentry
0216	Bathroom accessories, mirror
0217	Kitchen accessories, cabinets
0218	Drapery hardware
0219	Other exterior/interior repair, venetian blinds
0220	Garage door

03 Floor Coverings

0301	Resilient flooring
0302	Carpet and pad
0303	Ceramic flooring
0304	Underlayment/substrate
0305	Other flooring repairs

04 Interior Painting

0401	Walls and ceilings, incl. patching
0402	Trim
0403	Touch-up
0404	Bathtub/shower unit caulking
0405	Other Interior painting

05 Exterior Painting

0501	Walls, siding, incl. skirting
0502	Doors, frames, trim
0503	Exterior trim, incl. window, fascia, rake, soffit, etc.
0504	Caulking and sealing
0505	Glazing
0506	Other exterior painting

06 Heating

0601	Heating plant, valve
0602	Motors, blowers, pumps, G-60
0603	Ducts
0604	Piping
0605	Diffusers, grills
0606	Insulation
0607	Heating controls
0608	Other heating repairs, instructions for thermostat, turn on gas

07 Air Conditioning

0701	Cooling coils, compressor, condenser, valve, contactor
0702	Motors, blowers, pumps, transformer, fuses
0703	Piping, ducting
0704	Refrigerant
0705	Insulation
0706	Controls, delay module, relay
0707	Other cooling repairs, instruct thermostat use, filter

08 Plumbing

0801	Water heater
0802	Water softener
0803	Piping, supply, incl. valves, arrestors
0804	Faucets and shower heads
0805	Lavatories, incl. support and fasteners, caulking
0806	Water closets (i.e., toilets and commodes), incl. support and seals, caulking
0807	Bathtub/shower unit
0809	Other plumbing repair

09 Electrical

0901	Service entrance
0902	Panel box, incl. circuit breakers
0903	Branch circuits, incl. junctions, fasteners
0904	Wall receptacles and switches

0905	Doorbells, chimes
0906	Light fixtures
0907	Vents, fans
0908	Other electrical repair

10 Equipment

1001	Disposal
1002	Dishwasher
1003	Stove, range
1004	Range hood
1005	Refrigerator
1006	Other equipment

11 Utility Plant Equipment

Not applicable

12 Utility Service

1201	Water supply
1202	Gas supply
1203	Electrical service
1204	Sanitary/sewer
1205	Other utility service

13 Miscellaneous

APPENDIX D: Energy Efficiency Tests of 15 Conventionally Built Housing Units

The objective of these tests was to provide data concerning the energy efficiency of conventionally built housing. Tests were performed to determine the airtightness of the units (a measure of the resistance to air infiltration), furnace efficiencies, and heat transfer characteristics of the building envelope.

I. Tests Performed Upon Completion of Construction

Tests were conducted over 4 days in June 1983 on three types of buildings: a fourplex, a fiveplex, and a sixplex. Weather conditions were typical of the high desert area: light to negligible winds, clear skies, low humidity, and temperatures ranging from lows near 70 °F to highs near 110 °F.

House Tightness

A blower door apparatus was used to measure each unit's tightness. The blower door consisted of a variable speed fan, a digital tachometer to measure the fan blade rotation speed, and an inclined manometer to measure pressure differences. The fan could be operated to induce a positive or negative pressure difference in the house with respect to the outdoors.

To perform this test, the fan was fitted tightly into an outside door frame. A barbed fitting that penetrates the blower door was fitted with rubber tubing and connected to one side of the manometer. The other side of the manometer was open to the house. When the fan was operated, it could either force air into the house (pressurized) or force air out of the house (depressurized) depending on the direction of rotation. In either case, the pressure difference between the house and the outdoors could be read on the manometer. The fan speed was adjusted until a specified pressure difference existed (usually 0.1 or 0.2 in. of water). The fan speed required to achieve a given pressure was correlated to air flow, which indicated how tightly the house was sealed.

Each of the units was tested at 0.1 and 0.2 in. H_2O pressurized, and 0.2 in. H_2O depressurized. Some of the more obvious leaks (furnace room doors, dryer vents, attic doors) were then taped, and the house was again tested at 0.2 in. H_2O depressurized.

As shown in Table D1, airtightness was adequate, requiring no corrective work.

Furnace Efficiency

The furnaces in all the units were propane-fired. Tests were performed with a Fuel Efficiency Monitor (FEM), a hand-held automatic flue gas analyzer that measures the flue gas temperature, oxygen content, and ambient conditions and uses this information to calculate and display the percent efficiency of the furnace.

Each housing unit was first cooled down to allow the furnace to operate. The thermostats in the houses were of the "energy-saving" type, and included night setback and temperature limits. These were disconnected before each test so that the heating and air conditioning could be manually adjusted. The safety relief on the front of each furnace was covered so that room air would not be introduced into the flue. The furnace was then turned on, and a sample was taken of the intake air using the FEM. A 1/8-in.

Table D1

CBU Energy Efficiency Data After Construction

Building/Unit	UA* Btu/Hr-°F	No. Air Changes** Per Hour	Furnace*** Efficiency (%)
3720A	213	11.4	52.6
3720B	181	12.1	61.3
3720C	181	13.1	62.8
3720D	213	12.8	67.2
3720E	304	12.4	71.7
3720F	304	13.2	73.0
3724A	181	11.8	61.9
3724B	181	13.3	62.6
3724C	304	13.0	71.4
3724D	304	15.1	72.3
3725A	181	11.7	61.6
3725B	181	12.8	****
3725C	213	13.9	69.3
3725D	304	13.4	72.7
3725E	304	14.8	****

*These are calculated values based on the wall construction. U=heat transfer; A = area
**The following rating of air changes per hour at 0.2in. water column is based on work currently being done by Mansville Corp. for the U.S. Navy; 0 to 5, objectively tight; 5 to 10, excellent; 10 to 15, satisfactory; 15 and above merits corrective work.
***Most gas fired furnace manufacturers claim 80 percent efficiency.
****Unable to test furnace due to lack of access to the units.

hole was then drilled in the flue of the furnace. After allowing a few minutes for the furnace to reach steady state, the FEM probe was inserted into the flue pipe and a sample was taken of the exhaust gas. The FEM took 2 to 3 min to calculate the furnace efficiency. Table D1 shows the furnaces' operational efficiencies.

Wall Heat Transfer Characteristics

A Thermo Flow Energy Meter (TEM) was obtained to test the heat transfer characteristics of the walls. The TEM is an infrared radiometer that displays heat flow digitally in units of Btu/hr/sq ft. It can be used to detect insulation defects and to estimate the thermal resistance of exterior walls.

Due to unfavorable weather, the TEM could not be used to calculate R-values. The device was also useful for detecting insulation voids. No insulation voids were found.

II. Tests Performed after 5 Years' Occupancy

The house tightness and furnace efficiency tests were performed again in May 1988. Results are summarized below in Table D2. Again, no wall insulation tests were performed because of weather conditions.

Table D2

CBU Energy Efficiency Data 5 Years After Construction

Unit No.	No. Air Changes Per Hour	Furnace Efficiency (%)
3720A	11.0	58.5
3720B	11.4	68.6
3720C	12.9	65.8
3720D	10.2	70.6
3720E	10.6	74.2
3720F	10.8	59.5
3724A	10.6	68.9
3724B	11.6	57.8
3724C	14.4	67.4
3724D	12.3	70.4
3725A	11.3	66.0
3725B	11.8	24.1
3725C	14.4	68.8
3725D	16.2	67.3
3725E	12.4	74.5

APPENDIX E: Energy Efficiency Tests of 16 Manufactured Housing Units

The objective of these tests was to provide data on the energy efficiency of manufactured housing units for comparison to existing energy efficiency data taken on conventionally built housing units. Tests were performed to determine the airtightness of the units (a measure of the resistance to air infiltration), furnace efficiencies, and heat transfer characteristics of the building envelope.

I. Tests Performed Upon Completion of Construction

Tests were conducted on three types of fourplexes; Type I (Building 3809), II (Building 3802), and IV (Buildings 3800 and 3806). The tests were conducted over 4 days in April 1984. The weather during the testing was mild for high desert area; medium to strong winds, overcast skies, low humidity, and temperatures ranging from morning lows of 40 °F to highs near 80 °F.

House Tightness

To measure the tightness of each housing unit a blower door apparatus was used, as described in Appendix D.

Each of the manufactured housing units was tested at 0.1, 0.2, and 0.3 in. of water during pressurization and then tested at 0.1 and 0.2 in. under depressurization. Then air leaks were taped (furnace doors and kitchen vents) and the unit was retested at 0.2 in. during pressurization. During the final day the winds were gusting so high that no consistent manometer reading could be taken, so Building 3809 had no data for air infiltration.

The results of the USACERL testing, as presented in Table E1, demonstrate that the airtightness of all the units except one is acceptable. Unit 3800-C had a significantly higher value than the other units and should have corrective work done to improve its tightness.

During the airtightness testing, several leaks were found. In Type II, Unit 3802-C, serious leaks were found in the door to the furnace room. In Type IV, Units 3800 and 3806, leaks were found while depressurizing around the furnace vents and doors (Unit A in both buildings). Also, leaks were found around sliding doors (Unit 3800-C), kitchen window area (Unit 3806-D), utility outlets (Unit 3800-D), and a crack in the dining room wall (Unit 3806-D).

Furnace Efficiency

The furnaces in all of the units were propane-fired. Tests were performed using a FEM, as described in Appendix D. A carbon monoxide meter similar to the FEM was used to ensure that each furnace's burner was completely combusting its fuel and that there was no unusual concentration of carbon monoxide.

Table E1

MHU Energy Efficiency Data After Construction

Building/Unit	UA* Btu/Hr-°F	No. Air Changes Per Hour	Furnace Efficiency (%)
3800A	296	9.9	75.5
3800B	296	11.5	81.8
3800C	363	18.4	80.5
3800D	363	11.3	82.6
3802A	271	9.0	70.1
3802B	271	10.1	75.1
3802C	370	12.1	81.8
3802D	370	11.3	80.3
3806A	296	8.0	78.2
3806B	296	9.8	77.4
3806C	363	8.7	80.7
3806D	363	10.6	82.2
3809A	249	**	80.0
3809B	249	**	82.0
3809C	336	**	80.7
3809D	336	**	79.6

*These are calculated based on the wall construction. U = heat transfer coefficient; A = area.
**Unable to test airtightness due to high winds.

The testing was performed in the early morning hours so there would be a low outdoor temperature to start the furnace. The safety relief on the front of each furnace was taped over to prevent room air from entering the flue. A 1/8-in. hole was drilled into the flue near the furnace. The furnace was turned on and a sample of the ambient air was taken. The furnace was then left to reach steady state (approximately 15 min) and then the FEM probe was inserted into the hole and a sample of the exhaust gas was taken. The FEM took approximately 2 to 3 min to calculate and display the efficiency. Three samples were taken to ensure furnace steady state. The hole in the flue was then taped closed.

The furnace efficiencies are typical for the size and type of furnace installed.

Wall Heat Transfer Characteristics

A TEM, as described in Appendix D, was used to test the heat transfer characteristics of the exterior walls of each unit and to detect insulation defects.

This testing was done in the early morning hours because there must be a constant temperature difference of at least 20 °F between outdoor and indoor temperatures. First the outdoor and indoor temperatures were taken until they appeared steady. The TEM was then aimed at an interior wall and the net heat flow reading was recorded. Then the TEM was aimed at an exterior wall and the heat flow through the wall was recorded. Finally, the same measurement was made on the outside of the exterior wall (being sure that the area was shaded from sunlight). These results were used in conjunction with a standardized chart to determine the wall's thermal resistance. After these measurements were taken, the TEM was used to detect areas of high net flow readings, which indicate areas of insulation defects. There appear to be a number of insulation voids in Type I, II, and IV Units.

The UA values were calculated for the units, representing the overall heat transfer for the unit inclusive of walls, windows, doors, and roof (heat transferred from one unit to the next unit was considered negligible). The insulation voids listed in Table E2 were determined when the net heat flow varied by 10 Btu/hr-°F.

II. Tests Performed After 5 Years' Occupancy

The house tightness and furnace efficiency tests were performed again 5 years after construction. Results are given in Table E3.

Table E2

Insulation Void Locations

Building/Unit	Location of Void
3802A	Void area at upper left corner of window in front bedroom.
3802C	Void area above sliding glass door in dining room.
3802D	Void area at right electrical outlet in dining room.
3806C	Void areas in all wall-to-wall seams (corners).
3806D	Void areas in all wall-to-wall seams (corners).
3809B	Void area at upper right corner of sliding glass door in dining room.

Table E3

MHU Energy Data 5 Years After Construction

Building/Unit	No. Air Changes Per Hour	Furnace Efficiency (%)
3800A	7.8	75.9
3800B	9.4	80.2
380c0	*	76.3
3800D	10.2	72.8
3802A	9.6	71.2
3802B	10.2	80.4
3802C	10.8	79.1
3802D	*	*
3806A	8.6	79.9
3806B	10.3	77.1
3806C	11.4	79.8
3806D	12.9	76.6
3809A	7.4	78.7
3809B	7.0	73.9
3809C	10.2	79.2
3809D	10.3	78.3

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